METAL CUTTING AND MACHINE TOOLS

UNIT - I

Course Objectives

- To expose the students to the mechanics of metal cutting, so as to equip them with adequate knowledge about elements of metal cutting process.
- To emphasize upon the prominent theories, concepts and constructional features of machine tools related to turning, shaping, planning, drilling, milling and grinding operations.

Learning Outcomes

Upon successful completion of the course, the students will be able to

- Apply principles of metal cutting in machining operations.
- Calculate force, work done and power in metal cutting process using theories of machining process.
- Explain the components and operations of lathe machine.
- Select appropriate machine tool to process prismatic parts.
- Use principles of drilling, boring and milling in machining various components.
- Distinguish grinding, lapping and honing operations. Course Content

Syllabus:

Theory of Metal Cutting : Importance of material removal , elements of metal machining , tool, work, chip, fluid - types of cutting tools & tool materials , nomenclature of single point tool , systems of tool nomenclature , nomenclature of multi point tools ,milling cutter, drill, broach tool , orthogonal & obligue cutting , chip formation ,velocity relationships, types of chips , chip breakers.

Introduction:

It is extremely difficult to tell the exact number of various manufacturing processes existing and are being practiced presently because a spectacularly large number of processes have been developed till now and the number is still increasing exponentially with the growing demands and rapid progress in science and technology. However, all such manufacturing processes can be broadly classified in four major groups as follows:

No-cutting shaping:

No chip formation takes place, and the metal is shaped under the action of heat, pressure or both.

Ex: Forging, drawing, Spinning, Rolling, Extruding, etc.

Cutting shaping:

The components are brought to the desired shape and size by removing the unwanted material from the parent metal in the form of chips through machining.
Ex: Turning, Boring, Milling, Drilling, Shaping, Planning, Broaching, etc.

Importance of material removal

(a) Purpose of Machining Most of the engineering components such as gears, bearings, clutches, tools, screws and nuts etc. need dimensional and form accuracy and good surface finish for serving their purposes. Performing like casting, forging etc. generally cannot provide the desired accuracy and finish. For that such preformed parts, called blanks, need semi-finishing and finishing and it is done by machining and grinding. Grinding is also basically a machining process.

Machining to high accuracy and finish essentially enables a product

(1) Closer dimensional tolerances, surface roughness, or surface-finish characteristics may be required than are available by casting, forming, powder metallurgy, and other shaping processes; and

(2) Part geometries may be too complex or too expensive to be manufactured by other processes. However, machining processes inevitably waste material in the form of chips, production rates may be low, and unless carried out properly, the processes can have detrimental effects on the surface properties and performance of parts.

(3) Fulfill its functional requirements

(4) Improve its performance

Basic objectives of the economical and efficient machining practice :

- Quick Metal Removal (or MRR)
- High class surface finish
- Economy in tool cost
- Less power consumption
- Economy in the cost of replacement and sharpening of tools.
- Minimum deal time of machine tools.

Definition of Machining: Machining is an essential process of finishing by which jobs are produced to the desired dimensions and surface finish by gradually removing the excess material from the preformed blank in the form of chips with the help of cutting tool(s) moved past the work surface(s).

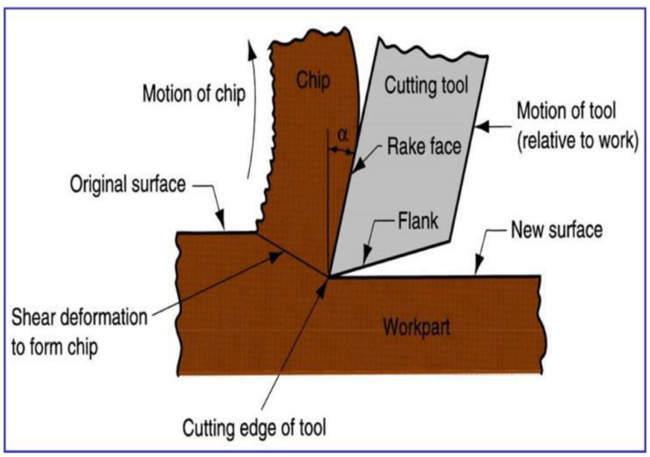
Definition of Machine Tool :

A machine tool is a non-portable power operated and reasonably valued device or system of devices in which energy is expended to produce jobs of desired size, shape and surface finish by removing excess material from the preformed blanks in the form of chips with the help of cutting tools moved past the work surface(s).

Basic Elements of Machining

The basic elements of machining operations are:

1. Work piece
2. Tool
3. Chip
4. Cutting fluid



For providing cutting action, a relative motion between the tool and work piece is necessary.

This relative motion can be provided by:

- Either keeping the work piece stationary and moving the tool. or
- By keeping the tool stationary and moving the work. or
- By moving both in relation to one another.

Influence of Parameters on Machining

The work piece provides the parent metal, from which the unwanted metal is removed by the cutting action of the tool to obtain the predetermined shape and size of the component.

The chemical composition and physical properties of the metal of the workpiece have a significant effect on the machining operation.

The tool material and its geometry are equally significant for successful machining.

The type and geometry of the chip formed are greatly effected by the metal of the work piece, geometry of the cutting tool and the method of cutting.

The chemical composition and the rate of flow of the cutting fluid also provide considerable influence over the machining operation.

CUTTING FLUIDS

Cutting fluids, frequently referred to as lubricants or coolants, comprise those liquids and gases which are applied to the cutting zone in order to facilitate the cutting operation. A cutting fluid is used
(1) To keep the tool cool and prevent it from being heated to a temperature at which the hardness and resistance to abrasion are reduced;
(2) To keep the workpiece cool, thus preventing it from being machined in a warped shape to inaccurate final dimensions;
(3) Through lubrication to reduce friction and power consumption, wear on the tool, and generation of heat;
(4) To provide a good finish on the workpiece;
(5) To aid in providing a satisfactory chip formation;
(6) To wash away the chips (this is particularly desirable in deep-hole drilling, hacksawing, milling, and grinding); and
(7) To prevent corrosion of the workpiece and machine tool.

Classification

Cutting fluids may be classified as follows: (1) emulsions, (2) oils, and (3) solutions (semisynthetics and synthetics).

Functions of a Cutting Fluid

To cool the tool and work piece.

- The cutting fluid employed at low temperature, as compared to the temperatures of the tool, work and chips.
- The heat generated flows from them outwards the fluid, which absorbs and drives it away along with it.
- The fluid is thus heated up and needs a constant replacement, by a fresh amount of cooler fluid.
- For this reason only a steady flow of the cutting fluid, in ample quantity is always needed during machining.

To provide adequate lubrication between the tool and the work piece and the tool and chips.

- It implies the reduction of friction between the tool and work piece and tool and chips.
- This helps in preventing a direct metal contact amongst the work piece, tool and the chip at the point where the three meet and also at the tool face.
- Which results in appreciable reduction in friction amongst these.

- A lesser amount of heat is generated and less power is consumed in the machine in metal cutting operation.

To prevent the adhesion of chips to the tool or work or both

- To prevent this, the addition of chemically active agents, like compounds of sulfur or chlorine are made to the cutting fluids.
- The compounds produce soapy films between the work and tool and chip and tool face.
- Which prevents the direct metal to metal contact, and hence, the chances of welding or adhesion.
- This film also provides lubrication, called *metal lubrication* between the mating surface.

Qualities of a good Cutting Fluid

1. It must carry away the heat generated during the process and thus, cool the tool and work piece both in order to minimize the tool wear and prevent distortion of the work piece.
2. It must provide sufficient lubrication between the tool and work and the tool and chips.
3. It should be capable of importing anti-welding properties to the tool and work.
4. It must carry such constituents which will prevent the finished work surface and the tool from the being rusted or corroded.
5. It should not discolor the finished work surface.
6. It should carry a fairly a mild smell.
7. It should not produce fog and smoke during use.
8. It should be non-poisonous and should not cause skin irritations.
9. Its flash point should be high enough

Types of Cutting Fluids:

- Straight oils
- Soluble oils
- Semisynthetic fluids
- Synthetic fluids

Straight oils are non-emulsifiable and are used in machining operations in an undiluted form. They are composed of a base mineral or petroleum oil and often contains polar lubricants such as fats, vegetable oils and esters as well as extreme pressure additives such as Chlorine, Sulphur and Phosphorus. Straight oils provide the best lubrication and the poorest cooling characteristics among cutting fluids. Synthetic Fluids contain no petroleum or mineral oil base and instead are formulated from alkaline inorganic and organic compounds along with additives for corrosion inhibition. They are generally used in a diluted form (usual concent ration = 3 to 10%). Synthetic fluids often provide the best cooling performance among all cutting fluids. Soluble Oil Fluids form an emulsion when mixed with water. The concentrate consists of a base mineral oil and emulsifiers to help produce a stable emulsion. They are used in a diluted form (usual concentration = 3 to 10%) and provide good lubrication and heat transfer performance. They are widely used in industry and are the least expensive among all cutting fluids. Semi-synthetic fluids are essentially combination of synthetic and soluble oil fluids and have characteristics common to both types. The cost and heat transfer performance of semi-synthetic fluids lie between those of synthetic and soluble oil fluids.

Coolants :-

The coolants are used to cool the tool, work piece and cutting elements. The following coolants are

1. Water
2. Soluble oils
3. Straight oils
4. Mixed oils
5. Chemical additive oils
6. Chemical compounds

1. **Water** :- water either plane or containing an alkaline, salt or water soluble additives. But little or no oil or soap or some times used only as a coolants. But water alone is in most cases objectionable for its corrosiveness.

2. **Soluble oils** :- soluble oils are emulsions composed of around 80% or more water, soap and mineral oils. The soap act as an emulsifying agent which brake the oil into particles to dispose through out the water.

3.**Straight Oils** :- the straight oils may be
(i).straight mineral oils (petroleum, kerosene, low viscosity petroleum fractions)
(ii).straight mixed oils or fatty oils consisting animal, vegetables etc. They have both cooling and lubricating properties and are used in lite machining.

4.**Mixed oil** :- This is a combination of straight mineral and straight fatty oils. This blend makes an excellent lubricate and coolant for automatic screw machining work and other lite machining operations when accuracy and good finish are of prime important.

5.**Chemical additive oils**: - Straight oil or mixed oil. When mixed up with sulphur or chorine is known as chemical additive oil sulphur and chlorine are used to increase both the lubricating and cooling particles.

6.**Chemical compounds** :- These compounds consists mainly of a rust inhabit or such as sodium, nitrate, mixed with high percentage of water chemical compounds have a good coolant particularly in grinding on machining surface. Where formation of rust is to avoided.

Classification of Cutting Tools:

The cutting tools used in metal cutting can be broadly classified as:

1. Single point tools : Those having only one cutting edge.
   Ex: Lathe tools, shaper tools, planer tools, boring tools, etc.

2. Multi-point tools: Those having more than one cutting edge.
   Ex: milling cutters, drills, broaches, grinding wheels, etc.

The cutting tools can be classified according to the motion as:

1. Linear motion tools:
   Ex: Lathe, boring, broaching, planing, shaping tools, etc.
2. Rotary Motion tools:
   Ex: milling cutters, grinding wheels, etc.
3. Linear and Rotary Motion tools:
   Ex: drills, honing tools, boring heads, etc.

Types of Cutting Tool Materials

Till about a century ago, most of the machining work was done with the help Cutting Tools made from plain carbon steel or an alloy steel, called Mushet steel, which was air-hardening alloy. But, their hot hardness's were too low and, therefore, high cutting speed could not be used. But, later developments in this field have give rise to the following cutting Tool Materials, which have much higher hot hardnesses and wear resistances. This has enables the use of much higher cutting speeds than the former.

- The main characteristics of a good cutting tool material are its hot hardness, wear resistance, impact resistance, abrasion resistance, heat conductivity, strength, etc.
- What is important to tool life is the likely changes in these characteristics at high temperature because the metal cutting process is always associated with generation of high amount of heat and, hence, high temperatures.
- The cutting speed has the maximum effect on tool life, followed by feed rate and depth of cut.
- All these factors contribute to the rise of temperature. That is why it is always said that ***an ideal tool material is the one which will remove the largest volume of work material at all speeds***.
- The tool material which can withstand maximum cutting temperature without losing its principal mechanical properties (specially hardness) and geometry will ensure maximum tool life, and, hence, will answer the most efficient cutting of metal.
- We, therefore, conclude that the ***higher the hot hardness and toughness in the tool material the longer the tool life***.

Characterristics of Cutting Tool Materials

The material used for the manufacture of cutting tools should posses the following characteristics:

1. Ability to retain its hardness at elevated temperatures, called ***hot hardness***.
2. Ability to resist shock, called ***toughness***.

3. High ***resistance to wear***, to ensure longer tool life.
4. Low ***coefficient of friction***, at the chip-tool interface, so that the surface finish is good and wear is minimum.
5. Should be ***cheap***.
6. Should be able to be ***fabricated*** and ***shaped easily***.
7. If it is to be used in the form of brazed tips, its other physical properties like tensile strength, thermal conductivity, coefficient of thermal expansion and modulus of elasticity, etc., should be as close to the shank material as possible to avoid cracking.

The following materials are commonly used for manufacturing the cutting tool selection of a particular material will depend on the type of service it is expected to perform.

➢ High Carbon Steel	➢High Speed Steel
➢ Coated H.S.S	➢Cemented Carbides
➢ Stellite,	➢Cemented Oxides or Ceramics, and
➢ Diamond	

High Carbon Steel

- ***Plain carbon steels*** having a carbon percentage as high as **1.5%** are in common use as tool materials for general class of work.
- However, they are not considered suitable for tools used in production work on account of the fact that they are not able to withstand very high temperature.
- With the result, they cannot be employed at high speeds.
- Usually the required hardness is lost by them as soon as the temperature rises to bout 200^0C – 250^0C.
- They are also not highly wear resistant.
- They are used mainly for hand tools.
- They are, however less costly, easily forgeable and easy heat treat.
- ***High carbon medium alloy steels*** are found to be more effective than plain high carbon steels.
- These steels, are provided better hot hardness, higher impact resistance, higher wear resistance etc., by adding small amounts of tungsten chromium, molybdenum, vanadium, etc., which improves their performance considerably and they are able to successfully operate up to cutting temperatures of 350^0C.

High Speed Steel (HSS)

- It is a special alloy-steel which may contain the alloying elements like tungsten, chromium, vanadium, cobalt and molybdenum, etc., up to 25 percent.
- These alloying elements increase its strength, toughness, wear resistance, cutting ability to retain its hardness at elevated temperatures in the range of 550^0C to 600^0C.

- On account of these added properties the high speed steel tools are capable of operating safely at 2 to 3 times higher cutting speeds than those of high carbon steel tools.
- The most commonly used high speed steel is better known by its composition of alloying elements as ***18-4-2*** i.e, the one that contains **18%W ,4% Cr and 1% V**.
- Another class of H.S.S. contains high proportions of cobalt (2 to 15%) and is known as cobalt H.S.S.
- It is highly wear resistance and carries high hot hardness.
- A highly tough variety of H.S.S., known as Vanadium H.S.S., carries 2%V, 6%W, 6% Mo and 4% Cr.
- It is widely favored for tools which have to bear impact loading and perform intermittent cutting.

Cemented Carbides

- The Everyday growing demand of higher productivity has given rise to the production of ***cemented or sintered carbides***.
- These carbides are formed by the mixture of tungsten, titanium or tantalum with carbon.
- The carbides, in powered form, are mixed with cobalt which acts as a binder.
- Then a ***powder metallurgy process*** is applied and the mixture, sintered at high pressures of 1500kf per sq. cm to 4000 kg per sq. Cm and temperatures of over 1500^0C, is shaped in to desired forms of tips.
- These carbide tips are then brazed or fastened mechanically (clamped) to the shank made of medium carbon steel.
- This provides an excellent combination of an extra-hard cutting edge with a tough shank of the tool.
- These cemented carbides posses a very high degree of hardness and wear resistance.
- Probably diamond is the only material which is harder than these carbides.
- They are able to retain this hardness at elevated temperatures up to 1000^0C.
- With the result, the tools tipped with cemented carbide tips are capable of operating at speeds 5 to 6 times (or more) higher than those with the high speed steels.
- It will be interesting to note at this stage that the best results with these tools can be obtained only when the machines, on which they are to be used, are of rigid construction and carry high powered motor so that higher cutting speeds can be employed.

Stellite

- It is a non-ferrous alloy consisting mainly of **cobalt, tungsten and chromium**.
- Other elements added in varying proportions are tantalum, molybdenum and Boron.
- It has good shock and wear resistance and retains its hardness at red heat up to about 920^0C.
- On account of this property, it is advantageously used for machining materials like hard bronzes, and cast and malleable iron, etc.
- Tools made of stellite are capable of operating at speeds up to 2 times more than those of common high speed steel tools.

- Stellite does not respond to the usual heat treatment process.
- Also, it can be easily machined by conventional methods.
- Only girding can be used for machining it effectively.
- A stellite may contain 40-50%Co, 15-35%Cr, 12-25%W and 1-4% carbon.

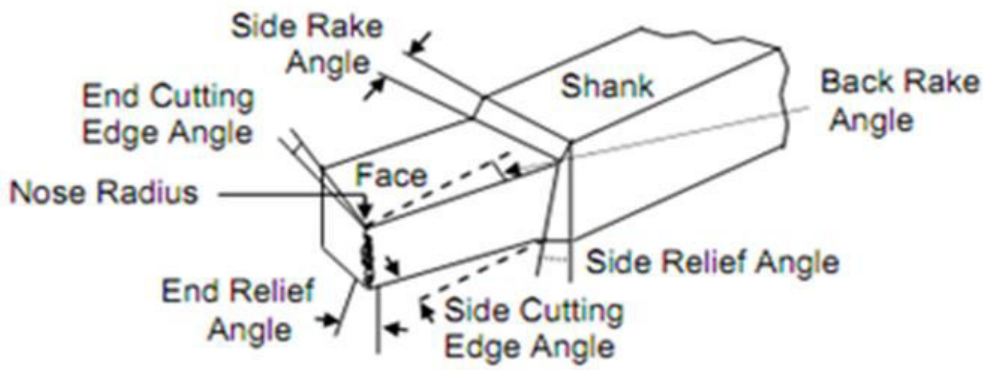
Cemented Oxides or Ceramics

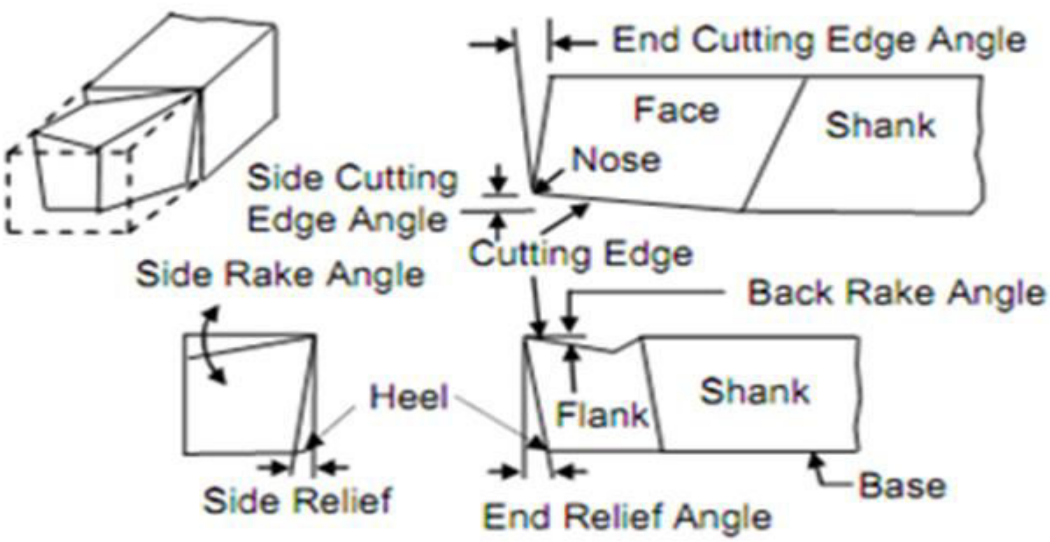
- The introduction of ceramic material as a useful cutting tool material is rather, a latest development in the field of tool metallurgy.
- It mainly consists of aluminum oxide (Al_2O_3), which is comparatively much cheaper than any of the chief constituents of cemented carbides.
- Boron nitrides in powdered form are added and mixed will aluminum oxide powder and sintered together at a temperature of about 1700^0C.
- They are then compacted into different tip shapes.
- Tool made of ceramic material are capable of withstanding high temperature, without losing their hardness, up to 1200^0C.
- They are much more wear resistant as compared to the cemented carbide tools.
- But at the same time, they are more brittle and possess low resistance to bending.
- With the result, they cannot be safely employed for rough machining work and in operations where the cut is intermittent.
- However, their application for finishing operations yields very satisfactory results.
- It is reckoned that, under similar conditions, the ceramic tool are capable of removing (MRR) 4 times material than the tungsten carbide tools with a consumption of 20 percent less power than the latter.
- They can safely operate at 2-3 times the cutting speeds of tungsten carbide tools.
- Ceramic tool material is used in the form of tips which are either brazed to the tool shank or held mechanically on them as the cemented carbide tips specially designed tool holders are also used for holding these tips.
- Usually no coolant is needed while machining with ceramic tools.

Diamond

- Diamond is the hardest material known and used as cutting tool material.
- It is brittle and offers a low resistance to shock, but is highly wear resistant.
- On account of the above factors diamonds are employed for only light cuts on material like Bakelite, carbon, plastics, aluminum and brass, etc.
- Because of their low coefficient of friction they produce a high grade of surface finish.
- However, on account of their excessively high cost and the demerits narrated above, they find only a confined use in tool industry.
- They are used in the form of bits inserted of held in a suitably designed wheel or bar.
- Diamond particles are used in diamond wheels and laps.

Nomenclature of single point tool





Shank: It forms the main body of a solid tool and it is this part of the tool which is gripped in the tool holder.

Face: It is the top surface of the tool between the shank and the point of the tool. In the cutting action, the chips flow along this surface only.

Point: It is the wedge shaped portion where the face and flank of the tool meet. It is the cutting part of the tool. It is also called nose.

Flank: Portion of the tool which faces the work is termed as flank. It is the surface adjacent to and below the cutting edge when the tool lies in a horizontal position.

Base: It is actually the bearing surface of the tool on which it is held in a tool holder or clamped directly in a tool post.

Heel: It is the curved portion at the bottom of the tool where the base and flank of the tool meet.

Nose Radius: If the cutting tip of a single point tool crries a sharp cutting point, the cutting tip is weak. It is therefore, highly stressed during the operation, may fail or lose its cutting ability soon and produce marks on the machined surface. In order to prevent these harmful effects the nose is provided with a radius. It enables greater strength of the cutting tip, a prolonged tool life and a superior surface finish on the workpiece. Also, as the value of this radius increases, a higher cutting speed can be used. But, if it is too large it may be lead to chatter. So, a balance has to be maintained. Its value normally varies from 0.4mm to 1.6mm, depending upon several factors like depth of cut, amount of feed, type of cutting, type of tool etc.

Principal Angles of Single Point Cutting Tool:

Rake angle: It is the angle formed between the face of the tool and a plane parallel to its base. If this inclination is towards the shank, it is known as *Back Rake or Top Rake*. When it is measured towards the side of the tool, it is called the *Side rake*. These rake angles guide the chips away from the cutting edge, thereby reducing the chip pressure on the face and increasing the keenness of the tool so that less power is required for cutting. It is important to note that an increased rake angle will reduce the strength of the cutting edge. With the result, the tools used for cutting hard metals are given smaller rake angles whereas those used for softer metals contain larger rakes.

Negative Rake: The rake angles discussed above are called positive rake angles. When no rake is provided on the tool, it is said to have a zero rake. When the face of the tool is so ground that it slopes upwards from the point it is said to contain a negative rake. It obviously reduces the keenness of the tool and increases strength of the cutting edge. Such a rake is usually employed on carbide tipped tools when they ar eused for machining extra hard surfaces. The value of this angle varies from 5^0 to 10^0.

Lip Angle: The angle between the face and and the falnk of the tool is known as Lip angle. It is also sometimes called the angle of Keenness of the tool. Strength of the cutting edge is directly effected by this angle. Larger the lip angle stronger will be the cutting edge and vice versa. This angle varies inversely as the rake angle. It is only for this reason that when harder metals ar eto be machined i.e., a stronger tool is required, the rake angle is reduced and consequently the lip angle is increased. This simultaneously calls for reduced cutting speeds, which is a disadvantage. The lip angle is therefore kept as low as possible without making the cutitng edge so weak.

Clearance Angle: It is the angle formed by the front or side surfaces of the tool which are adjacent and below the cutting edge when th etool is held in a horizontal position. It is the angle between one of these surfaces and a plane normal to the base of the tool. When the surface considered for this purpose is in front of the tool, i.e., just below the point, the angle formed formed is called Front Clearance and when the surface below the side cutting edge is considered the angle foremd is known as side clearance angle. The purpose of providing front clearance is to allow the toll to cut freely without rubbing against the surface of the job and that of the side clearance to direct the cutting thrust to the metal area adjacent to the cutting edge.

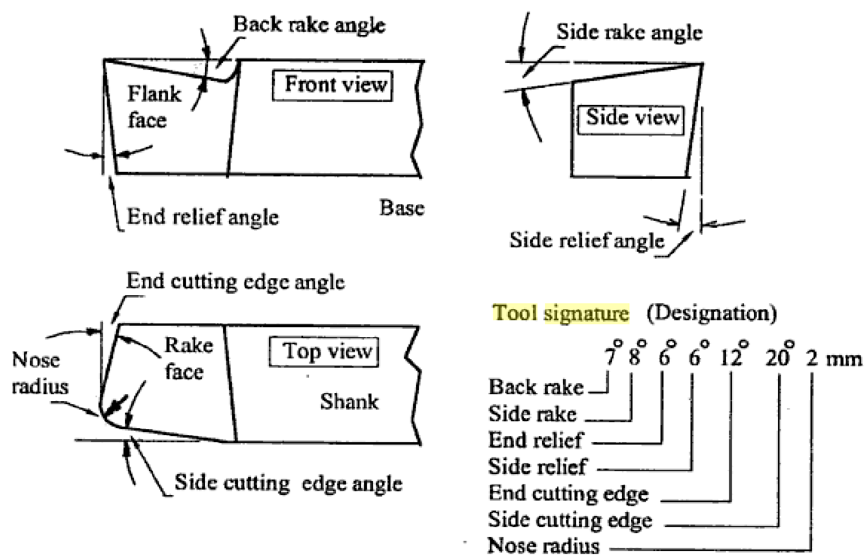
Relief Angle: It is the angle formed between the flank of the tool and a perpendicular line drawn from the cutting point to the base of the tool.
Cutting Angle: The total cutting angle of the tool is the angle formed between the tool face and a line through the point, which is a tangent to the machined surface of the work at that point. Obviously, its correct value will depend upon the poisition of the tool in which it is held in relation to the axis of the job.

Tool Signature:

- It indicates the angles that a tool utilizes during the cut.
- It specifies the active angles of the tool normal to the cutting edge.
- Some of the common systems are:
  - American System
  - British System
  - Continental System
  - International System

American System:

- It defines the principal angles like side rake, back rake, nose, etc. with regarding to the cutting edge and with out any reference to their locations.
- This system of nomenclature does not give any indication of the tool behavior with regard to the flow of chip during the cutting operation.
- The three reference planes adopted for designating different tool angles are similar to conventional machine drawing.



British System

- ➢ This system defines the Maximum Rake.
- ➢ The variation of tool parameters in this system are indicated in the order of :
  - Bake rake
  - Side rake
  - End Relief angle
  - Side relief angle
  - Side cutting edge angle
  - Nose radius

Continental System

- ➢ This system indicates the German System.
- ➢ The various tool parameters are specified with reference to the tool reference planes.

International System

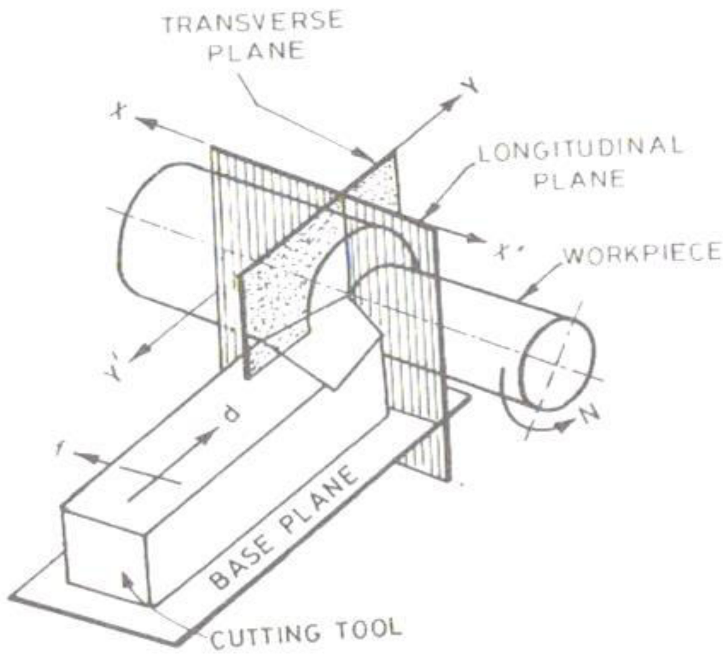
- It is internationally adopted system, developed recently.
- It incorporates the salient features of tool nomenclature of different systems in it.

Reference Planes:

The following two systems of reference planes are used to describe the geometry and locate the different parameters of a single point cutting tool.

- ➢ The Coordinate System
- ➢ The Orthogonal System

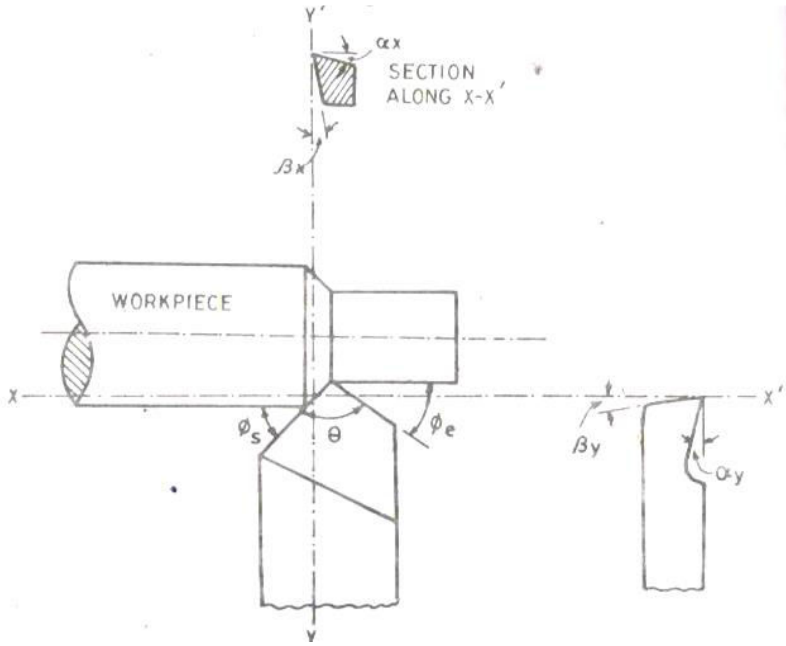
Coordinate System



- The tool being held in hand against a stationary work piece (Tool in Hand System).
- *Base plane* : The horizontal plane which contains the base of the shank of the cutting tool.
- *Longitudinal plane* : Vertical plane normal to the base plane and parallel to the direction of feed (*f*) .
- *Transverse Plane* : Plane perpendicular to the both the above reference planes and is parallel to the depth of cut (*d*).
- This combination of reference planes are known as *Coordinate System of Reference Planes.*

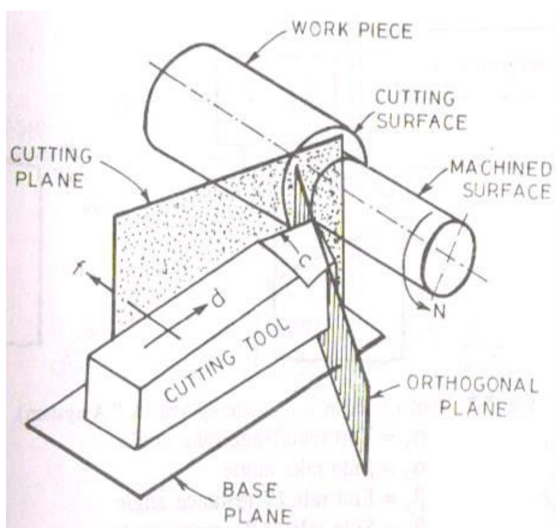
Tool Geometry in Coordinate System

- Also called as ASA System of tool signature.
- Because of the nomenclature of the reference planes X,Y,Z it also called as X-Y-Z Plane System.
- Various tool angles shown in figure are :
  α_y = Top Rake / Back Rake angle
  α_x = Side Rake angle
  β_y = End Relief / Clearance angle
  β_x = Side Relief / Clearance angle
  Φe = End Cutting Edge Angle
  Φ_s = Side Cutting Edge Angle
  θ = Nose Angle



- The order of representation of various parameters as:
  Back Rake , Side Rake, End Relief, Side Relief, End Cutting Edge, Side Cutting Edge, Nose Radius.
- The values of Nose Radius θ will depends on the values of Φe and Φ_s
- For Example:
  8,10,6,6,6,10,2

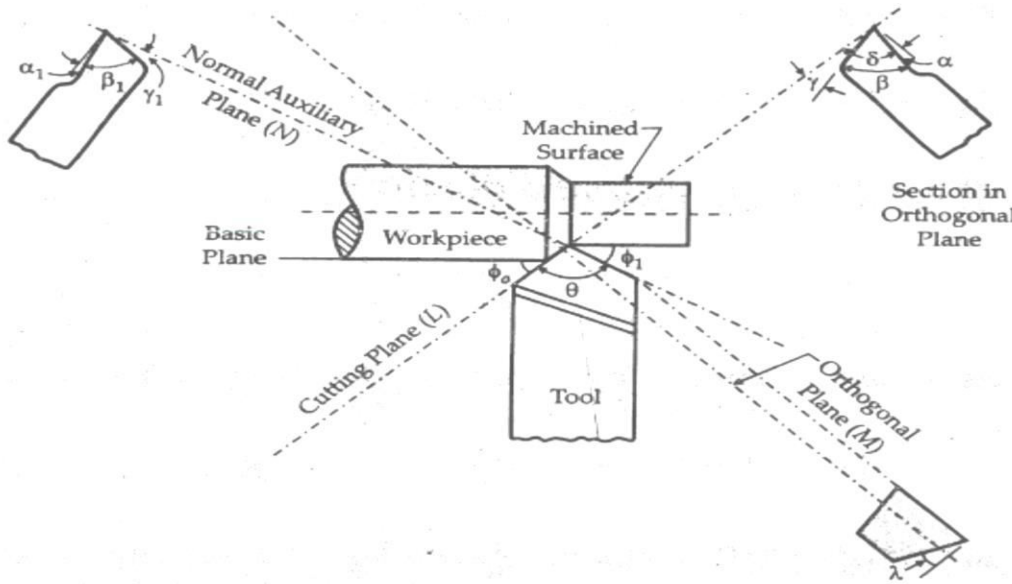
Orthogonal System



- This system assumed as the cutting tool is operating against the work piece.
- *Base Plane* : Horizontal Plane contains the base of the cutting tool.
- *Cutting plane* : Plane which is perpendicular to the base plane contains the principal cutting edge (c).

- *Orthogonal Plane*: third plane which is perpendicular to the both of the above planes.
- This set of reference planes is known as *Orthogonal System of reference planes*.

Tool Geometry in Orthogonal System



- Also called as *Orthogonal Rake System* (ORS) or *International System*.
- Because of the nomenclature of the reference planes L,M,N it also called as L-M-N Plane System.
- Due to the cutting tool operating on the work piece, many tool parameters are variables in this system.
- Their actual values are effected by the tool position with regarding to the work piece in actual operation.
- Various tool angles shown in figure are **:**

Φ_0 = Plane Approach angle	Φ_1 = Auxiliary cutting edge angle
λ = Angle of Inclination	α = Orthogonal Rake Angle
γ = Side Relif Angle	β = Wedge Angle
δ = Cutting Angle ($= \gamma + \beta$)	α_1 = Side Rake Angle
γ_1 = End Relief Angle	β_1 = Side Wedge Angle

- The order of representation of only main parameters as:
  Inclination, Orthogonal Rake, Side Relief, End Relief, Auxiliary Cutting, Approach, Nose Radius.
- For Example:
  0,10,5,5,8,90,1

Inter-Relationship Between ASA and ORS System

The following relationships will helps to convert some tool parameters from ASA to ORS.

$$\tan\alpha = \tan\alpha_y \bullet \cos\phi_0 + \tan\alpha_x \bullet \sin\phi_0 \qquad (1)$$

$$\tan\lambda = \tan\alpha_y \bullet \sin\phi_0 - \tan\alpha_x \bullet \cos\phi_0 \qquad (2)$$

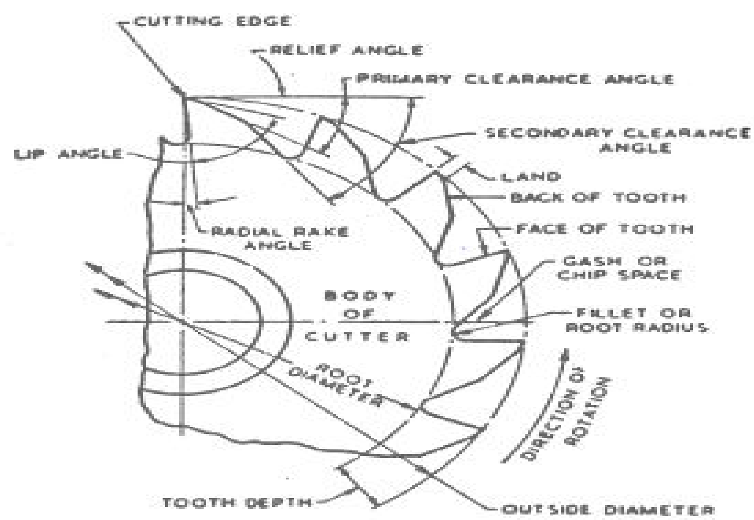
$$\tan\alpha_x = \sin\phi_0 \bullet \tan\alpha - \cos\phi_0 \bullet \tan\lambda \qquad (3)$$

$$\tan\alpha_y = \cos\phi_0 \bullet \tan\alpha + \sin\phi_0 \bullet \tan\lambda \qquad (4)$$

Nomenclature of multi point tools

Nomenclature of milling cutter:

The principal parts and angles of a plain milling cutter illustrated in figure are described below:



Elements of plain milling cutter

<u>*Body of Cutter*</u>: The part of the cutter left after exclusion of the teeth and the portion to which the teeth are attached.

<u>*Cutting edge*</u>: The edge formed by the intersection of the face and the circular land or the surface left by the provision of primary clearance.

<u>*Face*</u>: The portion of the gash adjacent to the cutting edge on which the chip impinges as it is cut from the work.

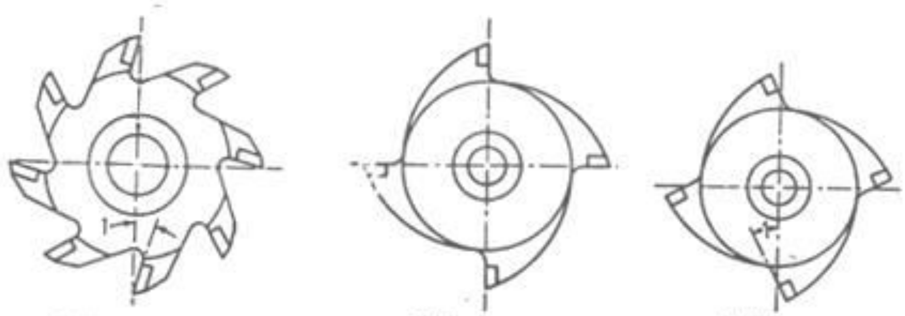
<u>*Fillet*</u>: The curved surface at the bottom a gash which joins the face of one tooth to the back of the tooth immediately ahead.

<u>*Gash*</u>: The chip space between the back of one tooth and the face of the next tooth.

<u>*Land*</u>: The part of the back of tooth adjacent to the cutting edge which is relieved to avoid interference between the surface being machined and the cutter.

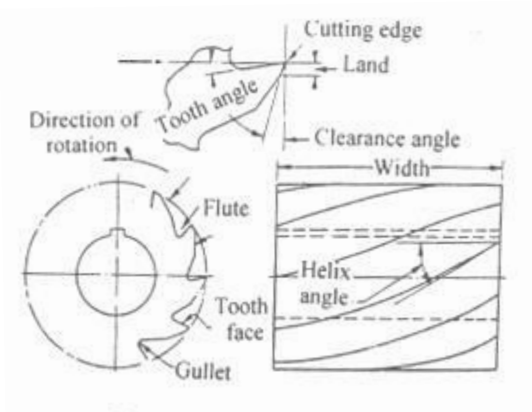
Lead: The axial advanced of the helix of the cutting edge in one complete revolution of the cutter.
Outside diameter: The diameter of the circle passing through the peripheral cutting edge.
Root diameter: The diameter of the circle passing through the bottom of the fillet.

Cutter angles: Similar to a single point cutting tool, the milling cutter teeth are also provided with rake, clearance and other cutting angles in order to remove metal efficiently. The following are the different cutter angles.
Relief angle: The angle in a plane perpendicular to the axis, which is the angle between the land of a tooth and the tangent to the outside diameter of cutter at the cutting edge of that tooth.
Primary clearance angle: The angle formed by the back of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.
Secondary clearance angle: The angle formed by the secondary clearance surface of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.
Rake angle (Radial): The angle measured in the diametral plane between the face of the tooth and a radial line passing through the tooth cutting edge. The rake angles which may be positive, negative or zero are illustrated in figures.



Milling cutter having positive rake | Milling cutter having zero rake | Milling cutter having negative rake

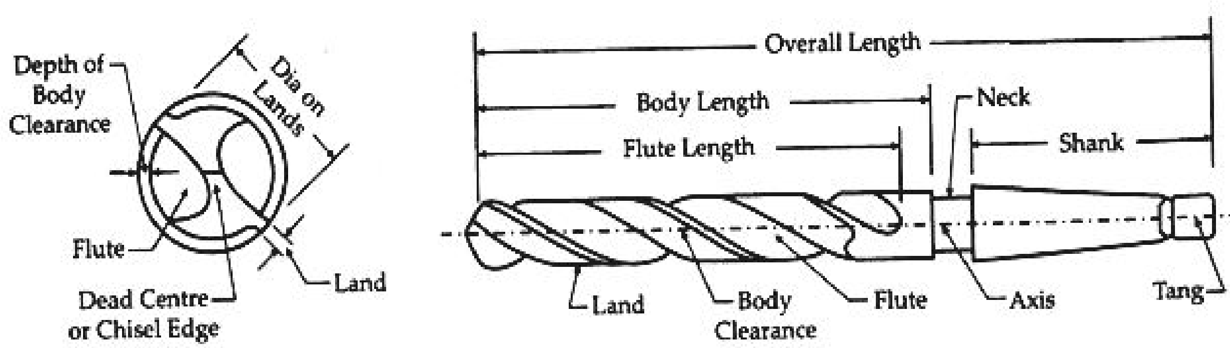
Zero rake: If the radial line and tooth face coincide in the diameter plane, the rake angle is zero.
Positive rake: If the tooth face is titled, so that the face and the tooth body are on the same side of the radial line, then the rake angle contained by the radial line and the tooth face is positive.
Negative rake: If the tooth face is titled, so that the face and the tooth body are on the opposite side of the radial line, then the rake angle contained by the radial line and the tooth face is negative.
Axial rake angle (for helical teeth): The angle between the line of peripheral cutting edge and the axis of the cutter when looking radially at the point of intersection.
Lip angle: The included angle between the land and the face of the tooth, or alternatively the angle between the tangent to the back at the cutting edge and the face of the tooth
Helix angle: The cutting edge angle which a helical cutting edge makes with a plane containing the axis of a cylindrical cutter. Figure illustrates the helix angle of a helical cutter.



Helix angle of helical cutter

Nomenclature of Drill;-

The Twist drill consists of two main parts viz., a shank, which is gripped in the Drill chuck or sleeve, and the other the body which formsthe main cutting unit.(See Figure).



The detailed description of the different parts of a twist drill, shown in Figs.7.2 and 7.3, and their functions are as follows:

Body: It is part of the drill which carries flutes and extends from the dead centre upto almost the start of the neck. This part of the drill is always relieved.

Axis: The longitudinal centre line of the drill, along which the whole body, neck and shank of the drill are concentric, is called the axis of the drill.

Chisel edge* or *dead centre: The short edge formed at the extreme tip end of the Drill, due to the intersection of the flanks, is called the chisel edge or dead centre. It coincides with the axis of the drill. Some of the drills carry a screw type or spiral shaped chisel edge instead of a sharp edge type. This facilitates more accurate location of holes and lower axial thrust.

Shank: The portion of the drill beyond the neck, which is gripped in the holding device (e.g., a drill chuck or sleeve, etc.), is called shank. It may be parallel or tapered.

Point: The cone shaped surface at the end of the flutes, formed by grinding, and containing the dead centre, lips and flanks, etc. is known as Point.

Lip* or *cutting edge: It is the main cutting part of the drill and is formed by the intersection of each flank and face. So, there will be so many lips in a drill as the number of flutes and the faces.

In a commonly used twist drill there are two lips because it carries two flutes and two corresponding flanks. For correct drilling it is essential that both lips should be of equal length and be equally inclined with the axis of the drill.

***Body Clearance*:** A small reduction in the diameter of the body is provided on a drill adjacent to the Land. This is called body clearance. It helps in reducing friction between the drill and the walls of the hole and, thus, helps in both metal cutting and increasing tool life.

***Land* or *Margin*:** It is a narrow flat surface which runs all along the flutes of the drill and its leading edges. The diameter of the drill measured across its lands determines its correct size. The functions of the lands are to keep the drill aligned during the operation and produce the correct size hole.

***Lip clearance*:** That part of the conical surface of point, which is ground to provide relief near the cutting edge, is called lip clearance.

***Face*:** The curved surface of the flute near the lip is called Face. The chips cut from the material slide upward along this surface.

***Flutes*:**The helical grooves in the body of the drill are known as flutes. Commonly used drills carry two flutes, while special drills any carry jour. These flutes make the chips curl and provide passage for their ext. Also, cutting edges are formed on the point due to machining of these flutes and the cutting fluid reaches the cutting area through these flutes only.

***Flank*:** It is the curved surface, on either side of the dead centre, which is confined between the cutting edge on its one side and the face of the other flute on the other side.

***Web*:** The central metal column of the drill body, that separates the flutes from one another, is known as Web. Its thickness gradually increases from the tip side towards shank side, where it is maximum. It is this part of the drill which is largely responsible for providing strength and rigidity to the drill.

***Chisel* edge**: The point of intersection of the chisel edge and the lip is known as chisel edge corner.

***Outer* corner:** The point extreme of the dead centre, where the face and flank intersect to form a corner, is called outer corner.

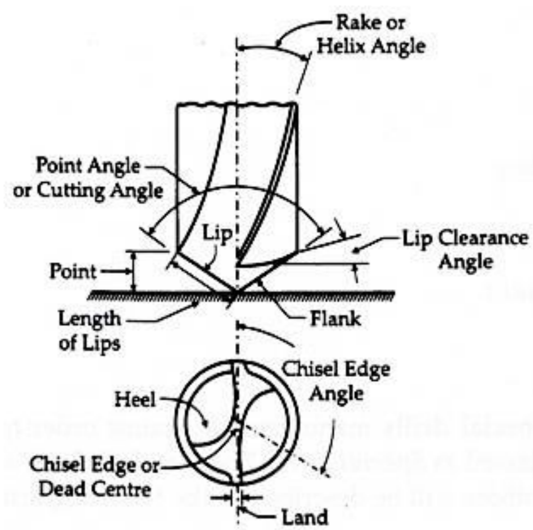
***Neck*:** The smaller diameter cylindrical portion which separates the body and shank of a drill is called neck. All necessary particulars of the drills are engraved on this portion.

***Tang*:** The flat portion of rectangular cross-section provided at the end of the tapered shank is known as Tang. This fits into a matching slot in the Holding device, such as a socket, sleeve or spindle, to provide a positive drive. Also, for driving the drill out of the sleeve or spindle, a drift is applied over this part of the drill.

***Heel*:** An edge is formed where the body clearance and flute of the drill intersect. This edge is known as Heel.

Important Angles of a Drill

Many different angles, as shown in figure, are provided on a drill so as to ensure an efficient metal cutting. The main angles are the following:



1. Rake angle or Helix Angle

It is also known as Helix angle. It is the angle formed between a plane containing the drill axis and the leading edge of the land. It can have a positive, negative or zero value. For a Right hand flute its value is positive, for a left hand flute negative and for parallel flutes it is zero. For most drills the value of rake angle varies from 0° to as high as 48°. However, 16° to 32° range is quite common for normal materials. Higher values are suitable for softer materials and lower valves for hander materials. The power or the torque required to rotate the drill is greatly influenced by this angle. Larger the value of the angle, lesser will be the torque required and vice-versa.

2. Point angle

It is also known a cutting angle. Its most commonly used value for a larger variety of materials is 118°. However it varies from 80° to 140°. Smaller point angle is favoured for brittle materials and the larger one for harder and tougher materials. It is the angle included between the two opposite lips of a drill, measured in a plane containing the axis of the drill and both the lips.

3. Lip clearance angle

The angle formed between the flank and a plane normal to the drill axis, measured at the periphery of the drill, is called chip clearance angle. Its value varies from 8° to 15° for most of the drills, but 12° angle is the most common. This angle is formed as a result of grinding the relief adjacent to the cutting edges to enable easy entry of the drill.

4. Chisel edge angle

When a drill is viewed from its end, there appears to be an obtuse angle formed between the lip and the chisel edge. This angle is called the chisel edge angle. It determines the clearance on the cutting lip near the chisel edge. The greater this angle the larger will be the clearance. Normally this angle varies between 120° and 135°, although on some smaller drills it may be as large as 145°.

The twist drills are made to carry one of the following two types of spiral grooves on the body :

1. HighHelix

They carry a Helix angle of 35° to 40° and a heavy web. Their groove width is larger than that of the usual twist drills and, therefore, they enable easier and quicker disposal of chips. They are largely employed for deep hole drilling, especially in low tensile strength materials like copper, aluminium, die casting alloys, plastics, wood, etc. They are also known as fast spiral drills.

2. LowHelix

They carry a smaller helix angle and are relatively more rigid. On account of their high rigidity, they are capable of taking higher torque and heavier feeds. They are widely used in general drilling work. They are also known as slow spiral drills.

Details Construction of Broach

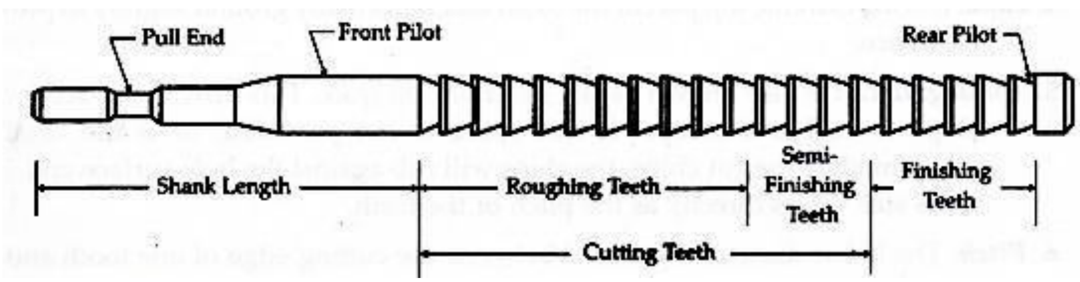
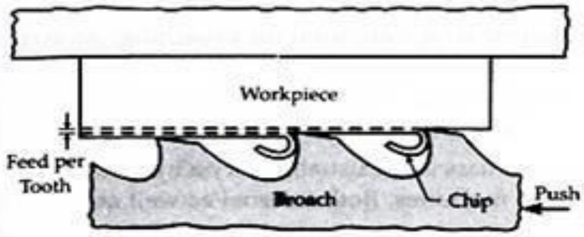
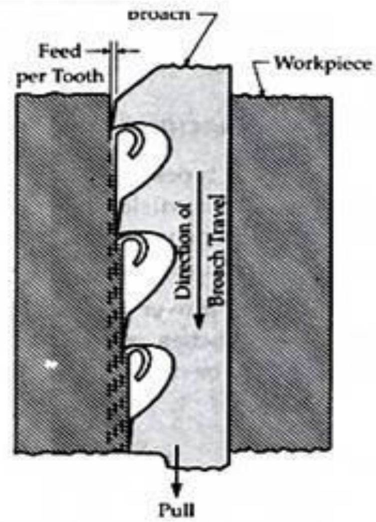


Figure illustrates the details of a pull type hole or internal broach for producing a cylindrical hole. The puller grips the broach at the shank end. Before the teeth, the front pilot enters the hole to keep proper alignment. The cutting teeth, which follow the front pilot, gradually increase in size. The first set of cutting teeth, called roughing teeth, does most of the cutting. They are followed by semi-finishing teeth, which remove comparatively less stock than the former. The variation in their sizes will obviously be smaller than the roughing teeth. They bring the size of the hole to roughly the required size. The finishing teeth, which follow after the semi-finishing teeth, do not practically remove any appreciable amount of stock. They are all of the same size and shape as the required size and shape of the hole, so as to produce the hole of required size and shape having a smooth finish. When the first finishing teeth are worn out, those behind them start doing the sizing operation. The rear pilot supports the broach and keeps it aligned after the cut is over.

Principle of Broaching



A Push type Broach in use for Machining an external surface.



A Pull type Broach in use for Internal broaching on a vertical pull-down type machine.

The operation of broaching involves the use of a multitooth cutter, called broach, which has already been described earlier. The teeth of the broach are so designed that the height of the cutting edge of the following cutting tooth is slightly more, equal to the feed per tooth, than that of the preceding tooth. Thus, when the broach is fed in a straight line, either over an external surface or through an internal surface, the metal is cut in several successive layers by successive teeth of the broach. The thickness of each layer is same and is known as feed per tooth. The sum of thicknesses of all the layers taken together is called the depth of cut.

During the operation, either the broach is fed past the stationary workpiece or the workpiece past a stationary broach, the former practice being more common. The surface produced carries an inverse profile to that of the broach teeth. A specific point regarding broaching is that out of all the basic machining processes it is the only process in which the feed is in-built in the tool (broach). This feed is equal to the chip thickness. This aspect is amply clear in the given diagrams.

Figure shows a push type broach being fed past the stationary work, on a horizontal broaching machine, to machine an external surface on the workpiece. Figure shows a pull type broach being fed into a hollow workpiece, on a vertical pull-down type machine, to machine an internal surface of the workpiece. In this case also, the workpiece will remain stationary. Both the operations are performed in a single linear stroke of the broach. After the end of the stroke in both the above operations the broach is retracted to the original starting position, the finished part replaced by a new workpiece and the operation repeated as usual.

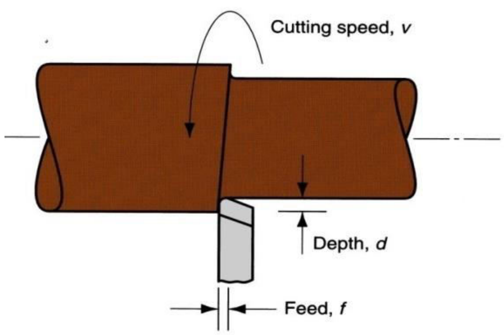
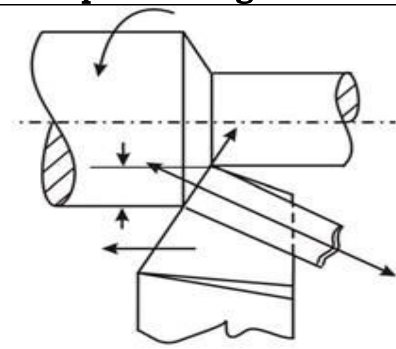
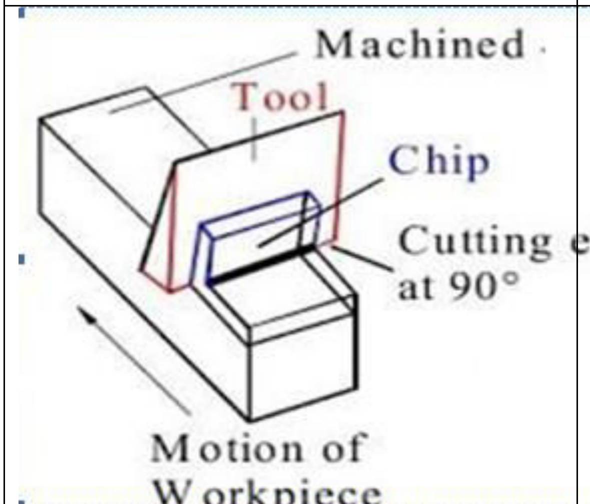
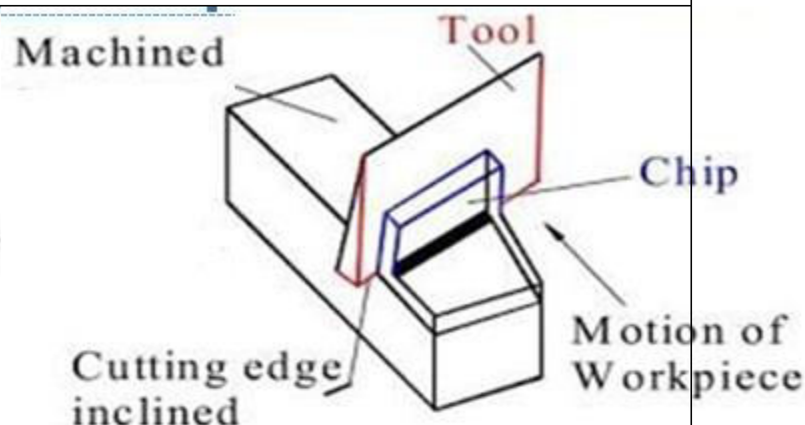
Orthogonal & Obligue Cutting:

Types of Cutting

Two types of cutting processes: 1. Orthogonal cutting

2. Oblique cutting

Difference between orthogonal cutting and oblique cutting:

Orthogonal Cutting	**Oblique Cutting**
	
	

Orthogonal Cutting

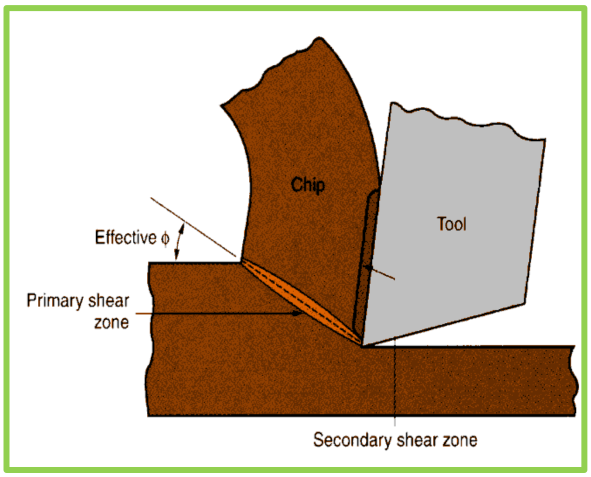
1. The cutting edge of the **tool** remains normal to the direction of tool feed or *workfeed*
2. The direction of the **chip flow velocity** is normal to the cutting ege of the **tool.**
3. The angle of inclination of the cutting ege of the tool with the normal to the velocity **Vc** is zero
4. The chip flow angle i.e, the angle between the direction of chip flow and the normal to the *cutting ege* of the tool, measured in the plane of the *tool face*, is zero.
5. The *cutting edge* is longer than the *width* of the cut.

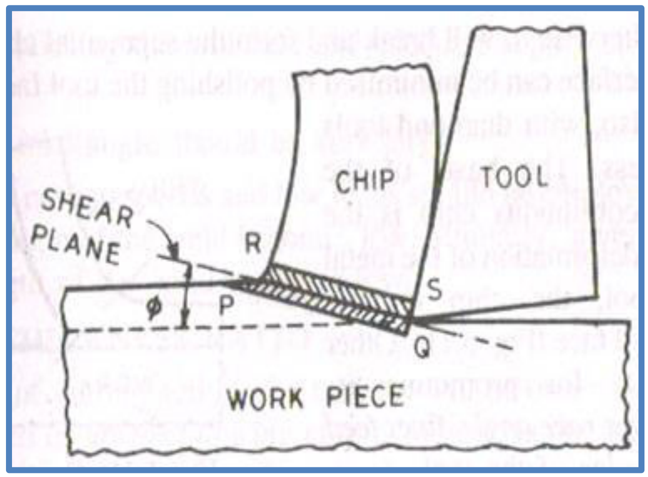
Oblique Cutting

1. The cutting ege of the tool always remains inclined at an acute angle to the direction of tool feed or work feed

2. The direction of the chip flow velocity is at an angle with the normal to the cutting edge of the tool. The angle is know as **Chip Flow Angle**
3. The cutting ege of the tool is inclined at an angle ***i*** with the normal to the direction of work feed or tool feed i.e the **Velocity Vc**
4. Three mutually perpendicular components of **Cutting Forces** act at the cutting edge of the tool.
5. The cutting edge may or may not be longer than the width of **cut**

Chip Formation

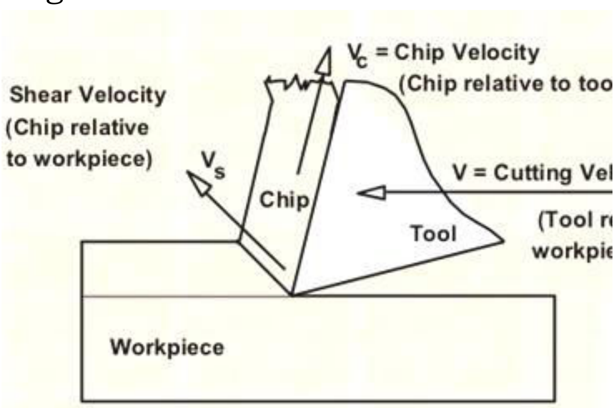


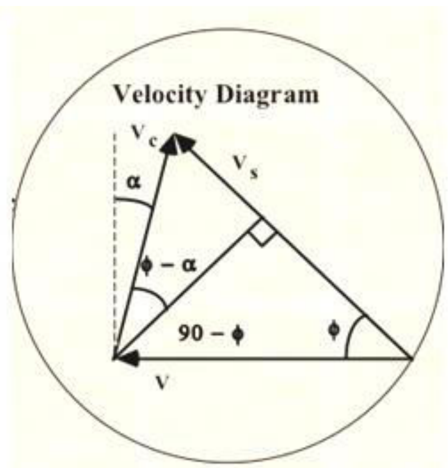


- The fig. represents the *shaping operation*, where the work piece remains stationary and the tool advances in to the work piece towards left.
- Thus the metal gets compressed very severely, causing *shear stress*.
- This stress is maximum along the plane is called *shear plane*.
- If the material of the workpiece is *ductile*, the material *flows plastically* along the shear plane, forming *chip*, which flows upwards along the face of the tool.
- The complete plastic deformation of the metal does not take place entirely along the shear plane only.
- It actually occurs over a definite area *PQRS*.
- The metal structure starts getting *elongated* along the line *PQ* below the shear plane and continues above the shear plane and continues up to the line *RS* where its deformation is completed.
- The complete area *PQRS* is known as *shear zone*.
- The shape of the shear zone is a *wedge shape*, with its thicker portion near the tool and the thinner one opposite to it.
- This shape of shear zone is one of the reasons to curl the chip.
- The produced chip is very hot and its safe disposal is very necessary.

The tool will cut or shear off the metal, provided by

- The *tool is harder* than the work metal,
- The tool is *properly shaped* so that its edge can be effective in cutting the metal,
- The tool is *strong enough* to resist cutting pressures but keen enough to sever the metal, and
- Provided there is *movement of tool* relative to the material or vice versa, so as to make cutting action possible.
  - **Velocity Relationships**
  - The relationship of different velocities for orthogonal is shown in figure. Let the velocities depicted in the diagram be as follows:



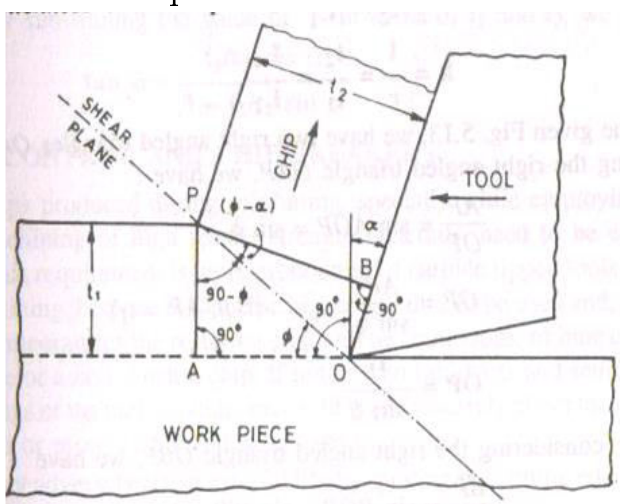


  - Analytically,
  - $$\frac{v_c}{\sin(90-(\varphi-\alpha))} = \frac{v_f}{\sin\varphi} = \frac{v_s}{\sin(90-\alpha)}$$
  - $$\frac{v_c}{\cos(\varphi-\alpha)} = \frac{v_f}{\sin\varphi} = \frac{v_s}{\cos\alpha}$$
  - $$v_f = \frac{v_c \sin\varphi}{\cos(\varphi-\alpha)}$$
  - $$v_f = v_c \times r \qquad \left(\because r = \frac{\sin\varphi}{\cos(\varphi-\alpha)}\right)$$
  - $$v_s = \frac{v_c \cos\alpha}{\cos(\varphi-\alpha)}$$

- Volume of material per unit time = Volume of material flowing up the chip
- $\Rightarrow v_c \times t_0 \times w = v_f \times t_c \times w$
- $\Rightarrow v_f = v_c \times r \quad \text{As, } r = \frac{t_0}{t_c}$

Chip thickness ratio

During the cutting action of a metal it will be observed that the thickness of the deformed or upward flowing chip is more than the actual depth of cut. It is because the chip flows upwards at a slower rate than the velocity of the cut. The velocity of the chip flow is directly affected by the shear plane angle. The smaller this angle the slower will be the chip flow velocity and therefore, larger will be the thickness of the chip.



t_1 = chip thickness prior to deformation

t_2 = chip thickness after deformation

- Thickness of the upward flowing chip is more than the actual depth of cut.

$$t_1 > t_2$$

- Because, *chip velocity < velocity of cut.*

Chip thickness ratio, $r = \frac{t_1}{t_2}$

Chip reduction coefficient, $k = \frac{1}{r} = \frac{t_2}{t_1}$

In orthogonal cutting the width of the chip equals the width of the cut. Considering the specific gravity of the metal as constant, the volume of the chip

produced will be equal to the volume of the metal cut. Widths of both being equal, the product of the chip thickness and its length will, therefore, be equal to the product of the thickness and the length of the metal cut. If L_1 and L_2 are the lengths of the metal cut and the chip respectively, it follows that:
Volume of the chip produced = Volume of the metal cut.

Volume= Width x thickness x length

$b_1 t_1 L_1 = b_2 t_2 L_2$

$t_1 L_1 = t_2 L_2$ $(b_1=b_2)$

$$\text{From the triangle OAP, } OP = \frac{t_1}{\sin\phi}$$

$$\text{From the triangle OBP, } OP = \frac{t_2}{\cos(\phi-\alpha)}$$

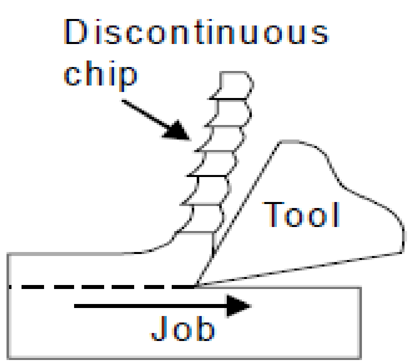
$$\text{Hence, } \tan\phi = \frac{r\cos\alpha}{1-r\sin\alpha}$$

Types of Chips

The chips produced during machining can be broadly classified as three types.

1. *Discontinuous or Segmental Chips*
2. *Continuous Chips*
3. *Continuous Chip with built-up edge*

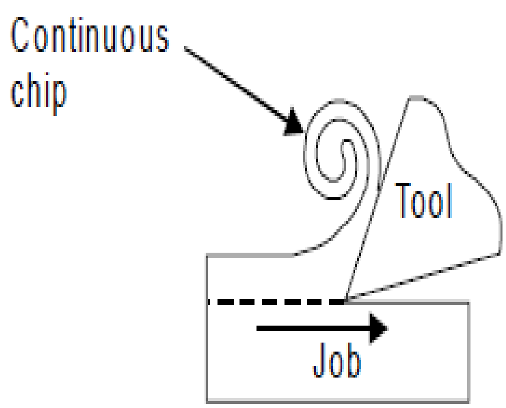
Discontinuous or Segmental Chips



- This type of chips produced during machining of brittle materials like cast iron and bronze.
- These chips are produced in the form of small segments.

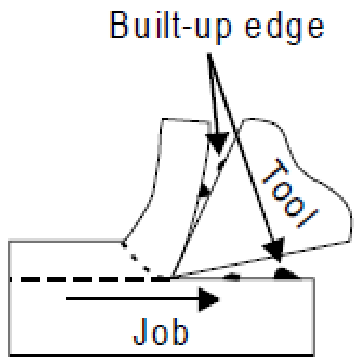
- As the tool advances forward, the shear plane angle gradually reduces until the value of compressive stresses acting on the shear plane becomes too low to prevent rupture.
- At this stage, any further advancement of the tool results in the fracture of the metal ahead of it, thus producing a segment of the chip.
- With further advancement of the tool, the processes of metal fracture and production of chips segments go on being repeated, and this is how the discontinuous chips are produced.
- These are also produced in machining of ductile materials when low cutting speeds are used adequate lubricant is not provided.
- This causes excessive friction between the chip and tool face, leading to the fracture of the chip in to small segments.
- This will also result in excessive wear on the tool and the poor surface finish on the work piece.
- *Other factors responsible* : smaller rake angle, too much depth of cut.

Continuous Chips



- The basis of the production of the continuous chip is the continuous plastic deformation of the metal ahead of the tool, the chip moving smoothly up the tool face.
- This type chip is produced while machining a ductile material, like mild steel, under favorable conditions, such as high cutting speeds and minimum friction between the chip and the tool face.
- The friction between the chip-tool interface can be minimized by polishing the tool face and adequate use of coolant.
- *Other factors responsible* : bigger rake angle, finer feed and keen cutting edge.

Continuous Chips with built-up edge



- While machining ductile material when high friction exists at the chip-tool interface results the continuous chips with built-up edge.
- The normal reaction of the chip on the tool face is quite high.
- It is maximum at the cutting edge or nose of the tool.
- This gives rise to an extensively high temperature and compressed metal adjacent to the tool nose gets welded to it.
- The chip is also sufficiently hot and gets oxidized as it comes off the tool and turns blue in colour.
- The extra metal welded to the nose of the tool is called built-up edge.
- While machining ductile material when high friction exists at the chip-tool interface results the continuous chips with built-up edge.
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- The chip is also sufficiently hot and gets oxidized as it comes off the tool and turns blue in colour.
- The extra metal welded to the nose of the tool is called built-up edge.
- Metal in built-up edge is highly strain hardened and brittle.
- During the chip flow up the tool, the built-up edge is broken and carried away with chip, rest of it bonded to the work piece and make it rough.
- Due to the built-up edge the rake angle also altered and so is the cutting force.
- *Other factors responsible* : low cutting speed, excessive feed, small rake angle, lack of lubricant.
- *Adverse effects of built-up edge formation*:
  - Rough surface finish.
  - Fluctuating cutting force, causing, vibrations in cutting tool.

  - Chances of carrying away some material from the tool by the built-up surface, producing *crater* on the tool face and causing tool wear.
- *Precautions to avoid built-up edge formation:*
  - The coefficient of friction at the chip-tool interface should be minimized by means of *polishing the tool face*.
  - Adequate supply of *coolant*.
  - *Large rake angle*.
  - *High cutting speeds* and *low feeds*.

Chip Control and Chip Breakers

- The chips produced during machining, specially while employing higher speeds in machining of high tensile strength materials, need to be effectively controlled.
- Higher speeds causing to higher temperatures resulting chip will be continuous, of blue colour and take the shape of coil.
- Adverse effect of coiled chips on machining:
  - Effects the tool life by spoiling the cutting edge, creating crater and rising the temperature.
  - Lead to poor surface finish on the work piece.
  - If the chip gets curled around the rotating w/p or tool, it may be hazardous the machine operator.
  - If a large and continuous coil is allowed to be formed, it may engage the entire machine and even the work piece, its quite dangerous.
  - Very large coils offer a lot of difficulty in their removal.
- Such difficulties are not encountered while machining materials like brass and cast iron.
- The ***chip breaker*** break the produced chips into small pieces.
- The work hardening of the chip makes the work of the chip breakers easy.
- If the job requirements do not call for very strict chip control the common methods used for chip breaking are :

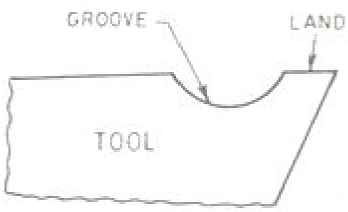
  By control of tool geometry :

  By grinding proper back rake and side rake according to the speeds and feeds.

  By obstruction method :

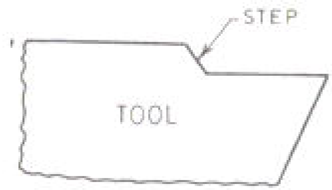
  By interposing a metallic obstruction in the path of the coil.
- When a strict chip control is desired, some sort of chip breaker has to be employed.
- The following types of chip breakers are commonly used.

1. Groove type



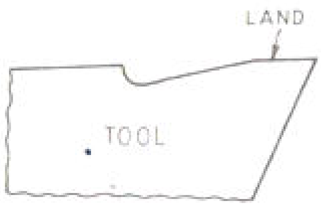
(a)

2. Step type



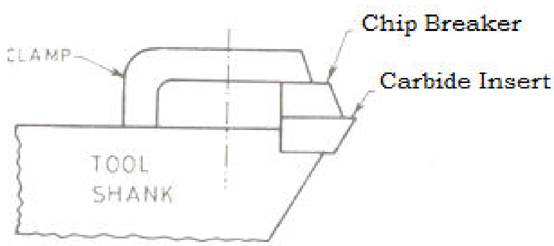
(b)

3. Secondary Rake type



(c)

4. Clamp type



(d)

Metal Cutting and Machine Tools

UNIT - II:

Mechanics of orthogonal cutting : Modern theories in Mechanics of cutting , review of Merchant and Lee Shaffer theories , stress, strain, workdone and power required in cutting , forces in turning, drilling and milling , cutting force measurement techniques ,dynamometers, machining parameters ,tool life ,effect of parameters on tool life ,tool failure.

Modern theories of Metal Cutting

Earnst-Merchant Theory

This theory, first proposed by Earnst and Merchant in 1941, is based on the principle of minimum energy consumption. It implies that during cutting the metal shear should occur in that direction in which the Energy requirement for shearing is minimum. The other assumptions made by them include :

(a) The behavior of the metal being machined is like that of an ideal plastic.

(b)At the Shear plane the Shear stress is Maximum, is Constant and Independent of Shear angle (Φ).

They deduced the following relationship:

$$\emptyset = \frac{\pi}{4} - \frac{\tau}{2} + \frac{\alpha}{2}$$

Lee and Shaffer's Theory

Lee and Shaffer analyzed the process of Orthogonal Metal Cutting by applying the Theory of plasticity for an ideal and rigid plastic material. The Principal Assumptions made by them include :

(a) The workpiece material ahead of the cutting tool behaves like an ideal plastic material.

(b) The deformation of the metal occurs on a single shear plane.

(c) There is a stress field within the produced chip which transmits the cutting force from the shear plane to the tool face and, therefore, the chip does not get hardened.

(d) The chip separates from the parent material (of the workpiece) at the shear plane.

Based on these assumptions, they developed a Slip-line Field for stress zone, in which no deformation would occur even if it is stressed to its yield point. From this, they derived the following relationship :

$$\emptyset = \frac{\pi}{4} + \alpha - \tau = 45^\circ + \alpha - \tau$$

$$\emptyset + \tau - \alpha = 45^\circ$$

Mechanics of Orthogonal Cutting

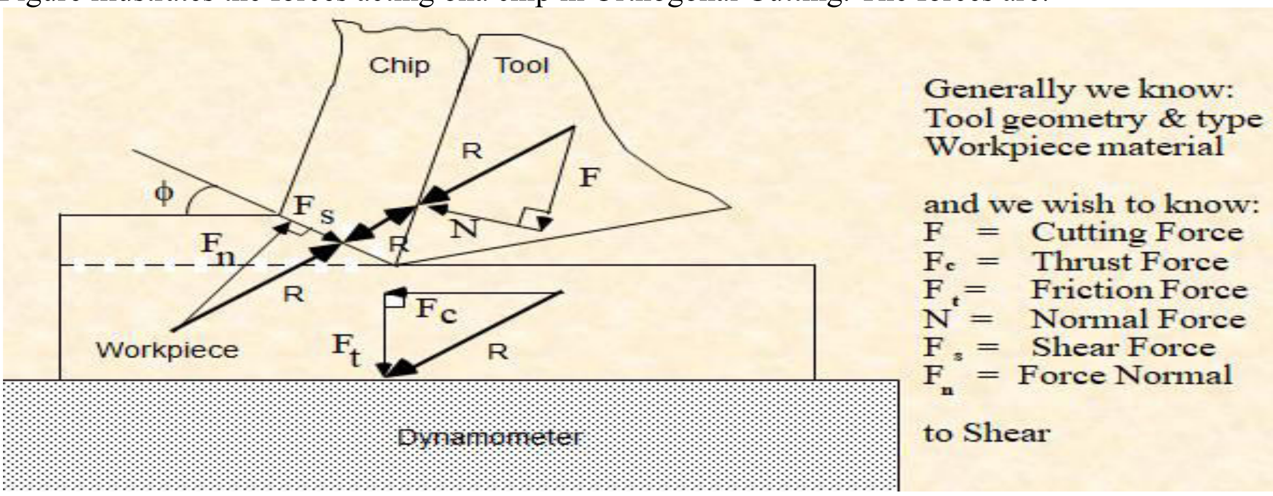
Force Relationship in Orthogonal Cutting:

The number of forces that act on the chip during the metal cutting process is shown in figure. The relationships among these forces were established by Merchant with the following assumptions:

- Cutting velocity always remains constant.
- Cutting edge of the tool remains sharp throughout cutting and there is no contact between the workpiece and tool flank.
- There is no sideways flow of chip.
- Only continuous chip is produced.

- There is no Buit-up-Edge.
- No consideration is made of the inertial force of the chip.
- The behaviour of the chip is like that of a free body which is in the state of a stable equlibrium due to the action of two resultant forces which are equal, opposite and collinear.

Figure illustrates the forces acting ona chip in Orthogonal Cutting. The forces are:



F_s – Metal resistance to shear in chip formation, acting along the shear plane,or **Shear Force**

F_n – Backing up force exerted by the workpiece on the chip, acting normal to the shear plane. N - Force exerted by the tool on the chip, acting normal to the tool face.

F = μN = Frictional resistance of the tool against the chip flow, acting alongthe tool face, μ being the coefficient of friction between the tool face and the chip.

These forces are vectorially represented in the free-body diagram shown in the figure. It will be observed that forces F_s and F_n can be easily repalced by their resultant R and forces F and N by their resultant R'. Thus, all these forces are resolved to only forces R' and R. For equlibrium, these forces R' and R should be equal, act opposite to each other and should be collinear.

$R' = F + N$ and $R = F_s + F_n$. For equilibrium, $R = R'$

For the convenience in establishing relationship, the two triangles of forces of the above free body diagram have beeen combined together, called the Merchant's Circle Diagram for cutting forces, in which two more force components are considered, which involved in cutting action.

Merchant's Circle:

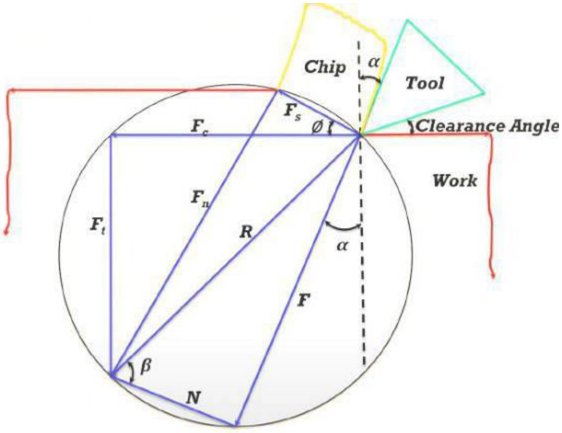
It is useful to determine the relation between the various forces and angles. In the diagram two force traingles have beeen combined and R and R' together have been repalced by R. The force R can be resolved into two components F_c and F_t.

F_c = Horizontal cutting force exerted by the tool on the workpiece

F_t = Vertical or tangential force which helps in holding the tool in position and acts on the tool nose.

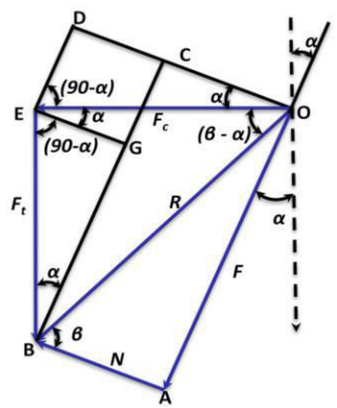
F_c and F_t can be determined by Force dynamometers.

Procedure to construct Mechant Force Circle:



- Set up x-y axis labled with forces, and represent the origin. The cutting force (F_c) is drawn horizontally, and the tangential force (F_t) is drawn vertically. Draw the resultant R of F_c and F_t.
- Locate the centre of R, and draw a circle that encloses vector R, i.e. the heads and tails of all three vectors will lie on this cirlce.
- Draw in the cutting tool in the upper right hand quadrant, taking care to draw the correct rake angle(α) from the vertical axis.
- Extend the line that is the cutting face of the tool(at the same rake angle) through the circle. This now gives the frictional force(F).
- A line can now be drawn from the head of the friction vector, to the head of the resultant vector(R). This gives the normal vector (N). Also add a friction angle (β) between vectors R and N. Therefore, mathematically $R = F_c + F_t = F + N$.
- Draw a vector from the origin towards the intersection of the two chip lines, stopping at the circle. The result will be a shear force vector (F_s). Also measure the shear force angle between F_s and F_c.
- Finally add the shear force normal(F_n) from the head of F_s to the head of R.
- The two forces F_c and F_t can easily be found out using force dynamometers. The angle α is a known quantity, being the rake angle of the tool. The value of Ø can also be determined using shear angle equation.
- When all these four values i.e F_c, F_t, α and Ø are known, all the other forces can be easily calculated with the help of geometry of the diagram as follows:

Frictional Force System:



F =OA=CB=CG+GB=ED+GB

$\Rightarrow F = F_C \sin\alpha + F_t \cos\alpha$

N= AB=OD–CD=OD–GE

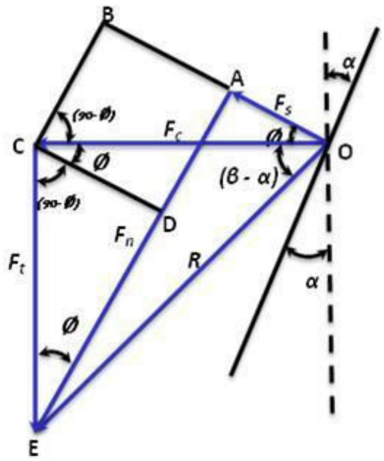
$\Rightarrow N = F_C \cos\alpha - F_t \sin\alpha$

The coefficient of friction, $\mu = \tan\beta =$

where β is the friction angle

$$\frac{F}{N}$$

Shear Force System:



$$F_S = OA = OB - AB = OB - CD \Rightarrow$$

$$F_S = F_C \cos\phi - F_t \sin\phi$$

$$F_N = AE = AD + DE = BC + DE \Rightarrow$$

$$F_N = F_C \sin\phi + F_t \cos\phi$$ Also, $F_n = F_s \tan(\phi + \beta - \alpha)$

and $\frac{F_t}{F_C} = \tan(\beta - \alpha)$

Relationship of various forces acting on the chip with the horizontal and vertical cutting force diagram:

$$F = F_C \sin\alpha + F_t \cos\alpha$$

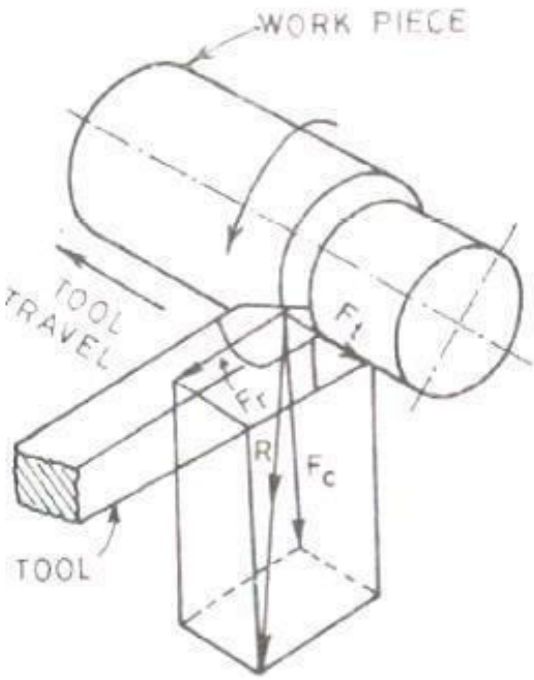
$$N = F_C \cos\alpha - F_t \sin\alpha$$

$$F_S = F_C \cos\varphi - F_t \sin\varphi$$

$$F_N = F_C \sin\varphi + F_t \cos\varphi$$

$$F_N = F_S \tan(\varphi + \beta - \alpha)$$

Forces on a single point cutting tool in turning:



- ***F_t*** = The ***feed force*** or thrust force acting in horizontal plane parallel to the axis of the work.
- ***F_r*** = The ***radial force,*** also acting in the horizontal plane but along a radius of the work piece. (*along the axis of the tool*)

F_c = The ***cutting force*** acting in vertical plane and is tangential to the work surface. (*also called as tangential force)*

Out of these three component forces, F_c is the largest and F_r the smallest. It has been found that the value of F_t for turning varies between $0.3F_c$ to $0.6F_c$ and that of F_r betweeen $0.2F_c$ to $0.4F_c$. In case of orthogonal cutting, only two component forces come into play since the value of F_r is zero in that case($F_r = 0$). In the present case of turning operation, the components F_c, F_t, and F_r can be easily determined with the help of suitable Force Dynamometers. Their resultant R can then be computed from the following relation:

$$R = \sqrt{F_c^2 + F_t^2 + F_r^2} \qquad R = \sqrt{F_c^2 + F_r^2}$$

Stress and Strain in the Chip

A chip is supposed to experience both the stress and strain during metal machining because it is produced as a result of plastic deformation of the metal. For calculating their values the conditions at the cutting plane are considered. Two mutually perpendicular forces F_s and F_n act on the shear plane. The average stresses on the shear plane are:

$$\textit{Mean}\text{ shear stress } \tau_s = \frac{F_s}{A_s} (kgf/mm^2)$$

$$\textit{Mean}\text{ normal stress } \sigma_s = \frac{F_n}{A_s} (kgf/mm^2)$$

where, F_s = shear force in kgs

F_n = normal force in kgs

A_s = Area of the shear plane $= \frac{A_0}{\sin \phi}$

where A_0 = Area of chip before removal = $t_1 w$

By substituting the values of F_s and A_s, we get

$$\tau_s = \frac{F_C \cos\varphi - F_t \sin\varphi}{t_1 w} . \sin\varphi \, kg/mm^2$$

$$\sigma_s = \frac{F_C \sin\varphi + F_t \cos\varphi}{t_1 w} . \sin\varphi \, kg/mm^2$$

Let the shear strain be γ,

Considering no loss of work during shearing

We Know,

Work done in shearing unit volume of the metal = shear stress × shear strain

$$\Rightarrow \frac{F_s \times v_s}{t_0 \times w \times v_c} = \tau_s \times \gamma$$

$$\gamma = \frac{F_s \times v_s}{\tau_s \times t_0 \times w \times v_c} = \frac{F_s \times v_s}{\frac{F_s}{A_s} \times t_0 \times w \times v_c} = \frac{F_s \times v_s}{\frac{F_s}{t_0 \times w / \sin\varphi} \times t_0} = \frac{v_s}{v_c} \times \frac{1}{\sin\varphi}$$

But $\frac{V_s}{v_c} = \frac{\cos\alpha}{\cos(\varphi - \alpha)}$, therefore

$$\Rightarrow \gamma = \frac{\cos\alpha}{\cos(\varphi - \alpha)\sin\varphi}$$

Work done in cutting:

The total work done = work done inshearing the metal+work done inovercoming the friction.

W =Total work done

W_s = Work donein shear

W_f = Work done against friction

$\therefore \; W = W_s + W_f$

f no work is lost,

total work done =work suplied by the motor

i.e., work suplied by the motor $= W_m = W_s + W_f$

$\therefore W = W_s + W_f = W_m$

W_m = work consummed in cutting + work spent in feeding

$= F_c \times V_c + F_t \times$feed velocity

F_t is very small compared to F_c ,

$\therefore \; W_m = F_c \times V_c$

$$\Rightarrow \qquad F_c \times V_c = W_s + W_f$$

now, $W_s = F_s \times V_s$ (shear force ×shear velocity)

$W_f = F \times V_f$ (frictional force × velocity of chip flow)

$\therefore \qquad F_c \times V_c = F_s \times V_s + F \times V_f$

Total work done per unit volume of metal removed in unit time :

$$= \frac{\text{Total work done in cutting per unit time}}{\text{volume of metal removed in unit time}} = \frac{F_c \times V_c}{A_0 \times V_c} = \frac{F_c}{A_0}$$

Horse Power Calculation:

$$\text{H.P. required in cutting} = \frac{\text{work done in cutting / min}}{4500}$$

$$= \frac{F \times V}{4500} \text{ h.p.} \quad \begin{cases} F \text{ in kgs} \\ V_c \text{ in m / min} \end{cases}$$

$$= \frac{F_c \times V_c}{4500 \times 1.36} \text{ kw.}$$

Cutting Speed

Cutting Speed of a Cutting Tool can be defined as the rate at which its cutting edge passes over the surface of the workpiece in unit time. It is normally expressed in terms of surface speed in Metres per minute.

It is a very important aspect in machining since it considerably affects the Tool life and efficiency of machining. Selection of a proper cutting speed has to be made very judiciously. If it is too high, the tool gets overheated and its cutting edge may fail, needing regrinding. If it is too low, too much time is consumed in machining and full cutting capacities of the tool and machine are not utilized, which results in lowering of productivity and increasing the production cost.

Feed

Feed of the Cutting Tool can be defined as the distance it travels along or into the workpiece for each pass of its point through a particular position in unit time. For example, in turning operation on a lathe it is equal to the advancement of the tool corresponding to each revolution of the work. However, it is computed and mentioned in different machine tools and different operations. For example, in planning it is the work which is feed and not the tool. Similarly, in Milling work involving the use of a Multi-point cutter, the feed is basically considered per tooth of the cutter. The cutting speed and feed of a Cutting Tool is largely influenced by the following factors :

- Material being machined
- material of the cutting tool.
- Geometry of the cutting tool.
- Required degree of surface finish.
- Rigidity of the machine tool being used.
- Type of coolant being used.

Depth of Cut

It is indicative of the penetration of the Cutting Edge of the tool into the workpiece material in each pass, measured perpendicular to the machined surface, i.e., it determines the thickness of metal layer removed by the cutting tool in one pass.

For example, in Turning operation on a lathe it is given by :

$$\text{Depth of Cut} = \frac{D - d}{2}$$

Where, D=Original diameter of the stock in mm
d=Diameter obtained after turning, in mm.

Tool Life

Tool Life can be defined as the Time Interval for which the tool works satisfactorily between two successive grindings (sharpening). The Tool Life can be effectively used as the basis to evaluate the performance of the tool material, assess machinability of the workpiece material and know the cutting conditions.

There are three common ways of expressing Tool Life:

1. As ***Time Period*** in minutes between two successive grinding.
2. In terms of ***Number of Components*** machined between two successive grindings. This mode is commonly used when the tool operates continuously, as in case of Automatic Machines.
3. In terms of the ***Volume of Material*** removed between two successive grindings. This mode of expression is commonly used when the tool is primarily used for heavy stock removal. The method of assessing the Tool Life in terms of the volume of material removed per unit of time is a practical one and can be easily applied as follows: Volume of metal removed per minute

$$= \pi D.t.f.N \text{ mm}^3/\text{min}$$

where, D = dia. of workpiece in mm, t= depth of cut in mm
f = feed rate in mm/rev. N = No. of revolutions of work per minute

If 'T' be the time in minutes to Tool failure, then,
Total volume of metal removed to tool failure

$$= \pi.D.t.f.N.T \text{ mm}^3$$

We also know that the Cutting Speed, = —— /
1000

∴ = × 1000

By substituting this value in equation, we get:
Total volume of metal removed to Tool failure

$$= V \times 1000 \times t \times f \times T \text{mm}^3$$

Therefore, Tool Life (T_L) in terms of the total volume of the metal removed to tool failure is given by : $\mathbf{T_L = V.1000.t.f.T \text{ mm}^3}$

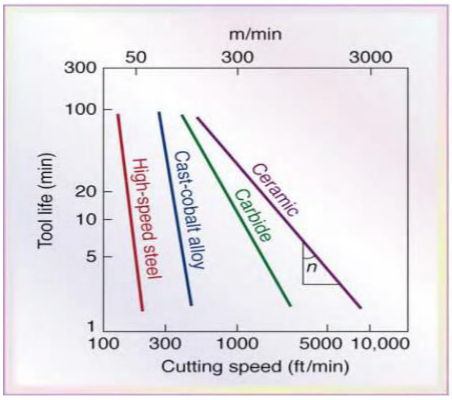
Factors Affecting Tool Life

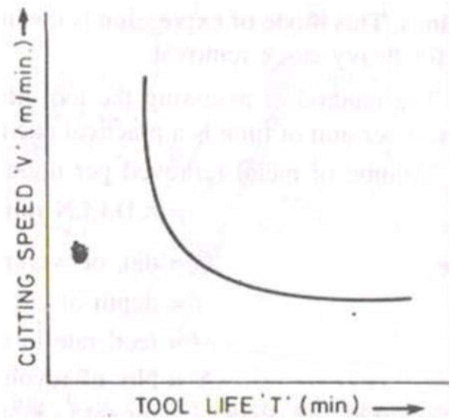
The Life of a Cutting Tool is affected by the following factors :

- Cutting Speed
- Tool Geometry
- Work material
- Rigidity of machine tool and work
- Feed and depth of cut
- Tool material
- Nature of cutting
- Use of cutting fluids

Cutting Speed

Out of all the above factors, the maximum effect on tool life is of Cutting Speed. The tool life varies inversely as the cutting speed i.e. the higher the cutting speed the smaller the tool life. Generally, the reduction in tool life corresponding to an increase in cutting speed is parabolic as shown in figure.





Based on the pioneer work of F.W Taylor, the relationship between cutting speed and tool life can be expressed as

$$VT^n = C$$

Where,

V= cutting speed in m/min

T=Tool life in min

C=A constant

(*numerically equal to cutting speed that gives the tool life in one min*)

n=A constant

(*depends on finish, workpiece material and tool material*)

n = 0.1 to 0.15 for HSS tools

= 0.2 to 0.5 for cemented carbide tools

= 0.6 to 1.0 for ceramic tools

Feed and Depth of Cut

Feed and depth of cut are the other important variables which also affect the tool life appreciably. An increase in the feed rate and depth of cut has similar effect i.e reduction in tool life, as is experienced by the tool when cutting speed is increased. The different variables, cutting speed, tool life, feed rate and depth of cut are inter-related as given in the following empirical formula:

$$V = \frac{257}{T^{0.19} \times f^{0.36} \times t^{0.80}} \text{ m / min}$$

where,

V = cutting speed in m /

min T = Tool life in min

f = Feed rate in mm / min

t = Depth of cut in mm

For given tool life,

$$V = \frac{C}{f^a \times t^b} \text{ m / min}$$

Where C = A constant

The exponent a and b depend upon the mechanical properties of the work material.

Tool Geometry

- Many geometrical parameters (tool angles) of a tool influence its performance and life.
- For example, the Ranke angle has a mixed effect.
- If it is increased in a positive direction the cutting force and the amount of heat generated are reduced.
- Obviously, this should help in increase the life of cutting tool.
- But, if it is very large the cutting edge is weakened and also its capacity to conduct heat is reduced.
- Thus, a considerable increase of the positive rake results in reduction of mechanical strength of the tool and, hence, lowering of tool life.
- Since the a above two effects are opposite to each other, for an effectively economical tool life it is necessary to strike a balance between the two, for which the optimum value of rake angle needs to be used.
- This value varies from -5^0 to $+10^0$.
- Cemented carbide and ceramic tools are generally provided negative rake**.**
- Similar contradictory effects are observed with the variations in relief angles or clearance angles.
- These angles are provided on the cutting tool to prevent rubbing of tool flank against the machined work surface.
- They, Thus, help in a very lowering the amount of heat generated and, therefore, increasing the tool life.
- But a very large relief angle results in weakening of tool and, hence, reduction of tool life.
- Again, therefore, a balance needs to be struck and only an optimum value should be used.
- These angles normally vary from 5^0 to 8^0, but in special cases, such as in carbide tipped tools, a higher value up to 10^0 can be used to prevent rubbing of shank.
- The two cutting edge angles also have their influence on tool performance.
- The front cutting edge angle, also known as end cutting edge angle, effects the tool wear.
- Up to a certain optimum value an increase in this angle permits the use of higher speeds without an adverse effect on tool life.

- But, an increase beyond that value will result in reduction of tool life. It generally varies from 5^0 to 8^0.
- The side cutting edge angle or the plane approach angle has a complex effect on tool life.
- This angle is smaller, higher speeds can be employed. A larger end cutting edge angle increase tool life.

Some other geometrical parameters effecting the tool life are:

a) Inclination angle: Tool life increase with the increase in this angle up to an optimum value.
b) Nose radius: While it increase abrasion, it also helps in improving surface finish and tool strength and, hence, the tool life.

Work Material

- The *microstructure of the work material* plays a significant role because it directly effects the hardness of the material.
- For example, presence of *free graphite and ferrite* in cast iron and steel imparts softness to them.
- *Pearlitic structure* is harder than this and the *martensitic structure* is the hardest.
- Similarly, *scale formation* and presence of oxide layer on the work surface serve as abrasives and, therefore, have a detrimental effect on tool life.
- Adverse effects on tool life are also experienced in machining if pure metal because of their tendency to stick to the tool face, specially at high temperature.
- This results in more friction and, hence, high amount of wear on tool and, therefore, a shorter tool life.

Narture of Cutting

- Toll life is also affected by the nature of cutting i.e. Whether it is continuous or intermittent.
- In the latter case, the tool is subjected to reaped impact loading and may give way much earlier than expected until it is made substantially strong and tough.
- In continuous cutting, a similar tool will have a relatively longer life.

Rigidity of Machine Tool and Work

- Both the machine tool and the work piece should remain rigid during the machining operation.
- If not, vibration will take place and then the cutting tool will be subjected to intermittent cutting instead of continuous cutting.
- This will result in impact loading of tool and, therefore, a shorter life.

Use of Cutting Fluids

- Cutting fluids are used in machining work for helping the efficient performance of the tool operation.
- They are used either in liquid or gaseous form.
- They assist in the operation in many ways, such as by cooling the tool and work, reducing friction, improving surface finish, helping in breaking of chips and washing them away, etc.
- These factors help in improving tool life, permitting higher metal removal rate and improving the quality of surface finish.

Types of Cutting Tool Materials

- The main characteristics of a good cutting tool material are its hot hardness, wear resistance, impact resistance, abrasion resistance, heat conductivity, strength, etc.
- What is important to tool life is the likely changes in these characteristics at high temperature because the metal cutting process is always associated with generation of high amount of heat and, hence, high temperatures.
- The cutting speed has the maximum effect on tool life, followed by feed rate and depth of cut.
- All these factors contribute to the rise of temperature. That is why it is always said that *an ideal tool material is the one which will remove the largest volume of work material at all speeds*.
- The tool material which can withstand maximum cutting temperature without losing its principal mechanical properties (specially hardness) and geometry will ensure maximum tool life, and, hence, will answer the most efficient cutting of metal.
- We, therefore, conclude that the ***higher the hot hardness and toughness in the tool material the longer the tool life***.

Characterristics of Cutting Tool Materials

The material used for the manufacture of cutting tools should posses the following characteristics:

1. Ability to retain its hardness at elevated temperatures, called ***hot hardness***.
2. Ability to resist shock, called ***toughness***.
3. High ***resistance to wear***, to ensure longer tool life.
4. Low ***coefficient of friction***, at the chip-tool interface, so that the surface finish is good and wear is minimum.
5. Should be ***cheap***.
6. Should be able to be ***fabricated*** and ***shaped easily***.
7. If it is to be used in the form of brazed tips, its other physical properties like tensile strength, thermal conductivity, coefficient of thermal expansion and modulus of elasticity, etc., should be as close to the shank material as possible to avoid cracking.

The following materials are commonly used for manufacturing the cutting tool selection of a particular material will depend on the type of service it is expected to perform.

➢ High Carbon Steel	➢ High Speed Steel
➢ Coated H.S.S	➢ Cemented Carbides
➢ Stellite,	➢ Cemented Oxides or Ceramics, and
➢ Diamond	

High Carbon Steel

- ***Plain carbon steels*** having a carbon percentage as high as **1.5%** are in common use as tool materials for general class of work.
- However, they are not considered suitable for tools used in production work on account of the fact that they are not able to withstand very high temperature.
- With the result, they cannot be employed at high speeds.
  - Usually the required hardness is lost by them as soon as the temperature rises to bout 200^0C– 250^0C.

They are also not highly wear resistant.

They are used mainly for hand tools.

They are, however less costly, easily forgeable and easy heat treat.

- ***High carbon medium alloy steels*** are found to be more effective than plain high carbon steels.
- These steels, are provided better hot hardness, higher impact resistance, higher wear resistance etc., by adding small amounts of tungsten chromium, molybdenum, vanadium,

  etc., which improves their performance considerably and they are able to successfully operate up to cutting temperatures of 350^0C.

High Speed Steel (HSS)

- It is a special alloy-steel which may contain the alloying elements like tungsten, chromium, vanadium, cobalt and molybdenum, etc., up to 25 percent.
- These alloying elements increase its strength, toughness, wear resistance, cutting ability to retain its hardness at elevated temperatures in the range of 550^0C to 600^0C.
- On account of these added properties the high speed steel tools are capable of operating safely at 2 to 3 times higher cutting speeds than those of high carbon steel tools.
- The most commonly used high speed steel is better known by its composition of alloying elements as ***18-4-2*** i.e, the one that contains **18%W ,4% Cr and 1% V**.
- Another class of H.S.S. contains high proportions of cobalt (2 to 15%) and is known as cobalt H.S.S.
- It is highly wear resistance and carries high hot hardness.
- A highly tough variety of H.S.S., known as Vanadium H.S.S., carries 2%V, 6%W, 6% Mo and 4% Cr.
- It is widely favored for tools which have to bear impact loading and perform intermittent cutting.

Cemented Carbides

- The Everyday growing demand of higher productivity has given rise to the production of ***cemented or sintered carbides***.
- These carbides are formed by the mixture of tungsten, titanium or tantalum with carbon.
- The carbides, in powered form, are mixed with cobalt which acts as a binder.
- Then a ***powder metallurgy process*** is applied and the mixture, sintered at high pressures of 1500kf per sq. cm to 4000 kg per sq. Cm and temperatures of over 1500^0C, is shaped in to desired forms of tips.
- These carbide tips are then brazed or fastened mechanically (clamped) to the shank made of medium carbon steel.
- This provides an excellent combination of an extra-hard cutting edge with a tough shank of the tool.
- These cemented carbides posses a very high degree of hardness and wear resistance.

- Probably diamond is the only material which is harder than these carbides.
- They are able to retain this hardness at elevated temperatures up to 1000^0C.
- With the result, the tools tipped with cemented carbide tips are capable of operating at speeds 5 to 6 times (or more) higher than those with the high speed steels.

- It will be interesting to note at this stage that the best results with these tools can be obtained only when the machines, on which they are to be used, are of rigid construction and carry high powered motor so that higher cutting speeds can be employed.

Stellite

- It is a non-ferrous alloy consisting mainly of **cobalt, tungsten and chromium**.
- Other elements added in varying proportions are tantalum, molybdenum and Boron.
- It has good shock and wear resistance and retains its hardness at red heat up to about 920^0C.
- On account of this property, it is advantageously used for machining materials like hard bronzes, and cast and malleable iron, etc.
- Tools made of stellite are capable of operating at speeds up to 2 times more than those of common high speed steel tools.
- Stellite does not respond to the usual heat treatment process.
- Also, it can be easily machined by conventional methods.
- Only girding can be used for machining it effectively.
- A stellite may contain 40-50%Co, 15-35%Cr, 12-25%W and 1-4% carbon.

Cemented Oxides or Ceramics

- The introduction of ceramic material as a useful cutting tool material is rather, a latest development in the field of tool metallurgy.
- It mainly consists of aluminum oxide (Al_2O_3), which is comparatively much cheaper than any of the chief constituents of cemented carbides.
- Boron nitrides in powdered form are added and mixed will aluminum oxide powder and sintered together at a temperature of about 1700^0C.
- They are then compacted into different tip shapes.
- Tool made of ceramic material are capable of withstanding high temperature, without losing their hardness, up to 1200^0C.
- They are much more wear resistant as compared to the cemented carbide tools.
- It is reckoned that, under similar conditions, the ceramic tool are capable of removing (MRR) 4 times material than the tungsten carbide tools with a consumption of 20 percent less power than the latter.
- They can safely operate at 2-3 times the cutting speeds of tungsten carbide tools.
- Ceramic tool material is used in the form of tips which are either brazed to the tool shank or held mechanically on them as the cemented carbide tips specially designed tool holders are also used for holding these tips.
- Usually no coolant is needed while machining with ceramic tools.

Diamond

- Diamond is the hardest material known and used as cutting tool material.
- It is brittle and offers a low resistance to shock, but is highly wear resistant.
- On account of the above factors diamonds are employed for only light cuts on material like Bakelite, carbon, plastics, aluminum and brass, etc.

- Because of their low coefficient of friction they produce a high grade of surface finish.
- However, on account of their excessively high cost and the demerits narrated above, they find only a confined use in tool industry.

Cutting Fluids

- The use of the metal working fluids is essential in all metal working operations.
- In metal machining, a lot of heat energy is generated proves harmful to the tool or work or both.
- These fluids help in minimizing these adverse effects and, thus, help to increase the *tool life* and *surface finish*.

Functions of a Cutting Fluid

To cool the tool and work piece.

- The cutting fluid employed at low temperature, as compared to the temperatures of the tool, work and chips.
- The heat generated flows from them outwards the fluid, which absorbs and drives it away along with it.
- The fluid is thus heated up and needs a constant replacement, by a fresh amount of cooler fluid.
- For this reason only a steady flow of the cutting fluid, in ample quantity is always needed during machining.

To provide adequate lubrication between the tool and the work piece and the tool and chips.

- It implies the reduction of friction between the tool and work piece and tool and chips.
- This helps in preventing a direct metal contact amongst the work piece, tool and the chip at the point where the three meet and also at the tool face.
- Which results in appreciable reduction in friction amongst these.
- A lesser amount of heat is generated and less power is consumed in the machine in metal cutting operation.

- To prevent this, the addition of chemically active agents, like compounds of sulfur or chlorine are made to the cutting fluids.
- The compounds produce soapy films between the work and tool and chip and tool face.
- Which prevents the direct metal to metal contact, and hence, the chances of welding or adhesion.
- This film also provides lubrication, called *metal lubrication* between the mating surface.

Qualities of a good Cutting Fluid

1. It must carry away the heat generated during the process and thus, cool the tool and work.
2. It must provide sufficient lubrication between the tool and work and the tool and chips.
3. It should be capable of importing anti-welding properties to the tool and work.
4. It should not discolor the finished work surface.
5. It should carry a fairly a mild smell.
6. It should not produce fog and smoke during use.
7. It should be non-poisonous and should not cause skin irritations.
8. Its flash point should be high enough

Types of Cutting Fluids:

- Straight oils
- Soluble oils
- Semisynthetic fluids
- Synthetic fluids

- ***Straight oils*** are non-emulsifiable and used in machining operations in an undiluted form.
- They are composed of a base mineral or petroleum oil and often contains polar lubricants such as fats, vegetable oils and esters as well as extreme pressure additives such as Chlorine, Sulphur and Phosphorus.
- Straight oils provide the best lubrication and the poorest cooling characteristics.
- ***Synthetic Fluids*** contain no petroleum or mineral oil base and instead are formulated from alkaline inorganic and organic compounds along with additives for corrosion inhibition.
- They are generally used in a diluted form (usual concent ration = 3 to 10%). Synthetic fluids often provide the best cooling performance among all cutting fluids.
- ***Soluble Oil*** Fluids form an emulsion when mixed with water.
- The concentrate consists of a base mineral oil and emulsifiers to help produce a stable emulsion. They are used in a diluted form (usual concentration = 3 to 10%) and provide good lubrication and heat transfer performance.
- They are widely used in industry and are the least expensive among all cutting fluids.
- ***Semi-synthetic fluids*** are essentially combination of synthetic and soluble oil fluids and have characteristics common to both types.

MACHINABILITY

- *Machinability of a material gives the idea of the ease with which it can be machined.*
- The parameters generally influencing the machinability of a material are:
  1. Physical properties of the material 2.Mechanical properties of the material
  3. Chemical composition of the material 4.Micro-structure of the material
  5. Cutting conditions
- Since this property (machinability) of the material depends on various variable factors, it is not possible to evaluate the same in terms of precise numerical values, but as a relative quantity. The criteria of determining the same may be as follows:

1. Tool life - The longer the tool life it enables at a given cutting speed the better is the machinability.
2. Surface finish – It is also directly proportional i.e., the better the surface finish the higher is the machinability.
3. Power consumption – Lower power consumption per unit of metal removed indicates better machinability.
4. Cutting forces – The lesser the amount of cutting force required for the removal of a certain volume of metal or the higher the volume of metal removed under standard cutting forces the higher will be the machinability.
5. Shear angle – Larger shear angle denotes better machinability.

MACHINABILITY INDEX

- The machinability for different materials are compared in terms of their machinability indexes.
- For this purpose the machinability index of ***free cutting steel*** serves as datum, with reference to which all other machinability indexes are compared.

The machinability index of this steel is taken as ***100***.

$$\text{Machinability Index (\%)} = \frac{\text{Cutting speed of material for20min.tool life}}{\text{Cutting speed of standard free-cutting steell for20min.tool life}} \times 100$$

TOOL DYNAMOMETERS

In a Machining or Metal cutting operation the device used for determination of Cutting Forces is known as a Tool Dynamometer, Metal Cutting Dynamometer or Force Dynamometer. The Forces which are normally required to be measured are the Cutting force (Fc),Tangential force (Ft) and shear force (Fs).It is because the values of these forces are widely used in the calculations for finding out other Forces with the help of equations derived in earlier articles. Majority of the Dynamometers used for measuring the Tool forces use the deflections or strains caused in the components, supporting the tool in metal cutting, as the basis for determining these forces. In order that a Dynamometer gives satisfactory results it should possess the following important Characteristics :

- It should be sufficiently rigid to prevent vibrations.
- At the same time it should be sensitive enough to record deflections and strains appreciably, a characteristics contradictory to the first one.
- Its design should be such that it can be assemble and dissemble easily
- A simpler design is always preferable because it can be used easily
- It should preferably be so designed that when one force component is being measured the other force Component should not show any readings
- It should possess substantial stability against variations in time, temperature, humidity, etc.
- It should be perfectly reliable.
- The metal cutting process should not be disturbed by it , i.e., no obstruction should be provided by it in the path of the chip flow or tool travel
- Its fabrication and calibration should be easy.

The various requirements, some of which are mutually contradictory, impose number of constraints on the design of Dynamometers. As such, the endeavour always should be to strike the best possible compromise under the given conditions. Dynamometers are made in different grades of accuracies according to the purpose for which they are to be used, as follows :

GRADDE	ACCURACY
Workshop or Regular	±5.0%
Calibration	±1.0%
Research	±0.5%

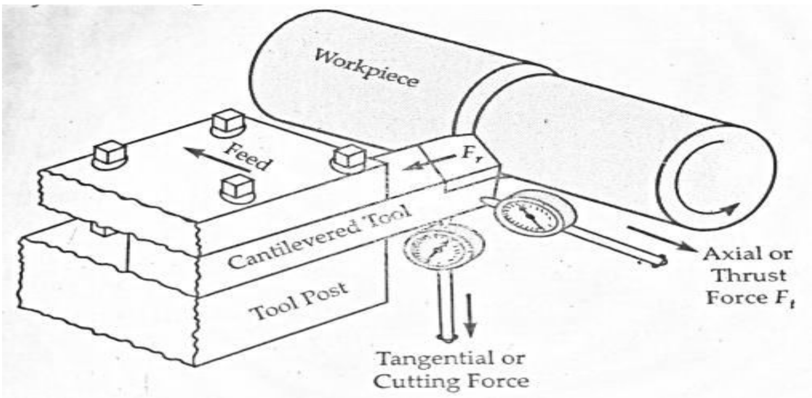
TYPES OF DYNAMOMETERS

Irrespective of their design and the technique used for strain measurement, most of the Force Dynamometers used today carry a Measuring system which is pre-calibrated for its stiffness. The cutting forces are measured by these Dynamometers by measuring the strain or deflection caused in this system due to the force under measurement. One of the simplest and most commonly employed systems is a Measuring spring , whose deflection is calibrated to indicate the corresponding cutting force. The different types of commonly used Dynamometers can be broadly classified as :

1. Mechanical Dynamometers.
2. Strain gauge type Dynamometers.
3. Pneumatic and Hydraulic Dynamometers.
4. Electric Dynamometers
5. Piezoelectric Dynamometers.

MECHANICAL DYNAMOMETERS

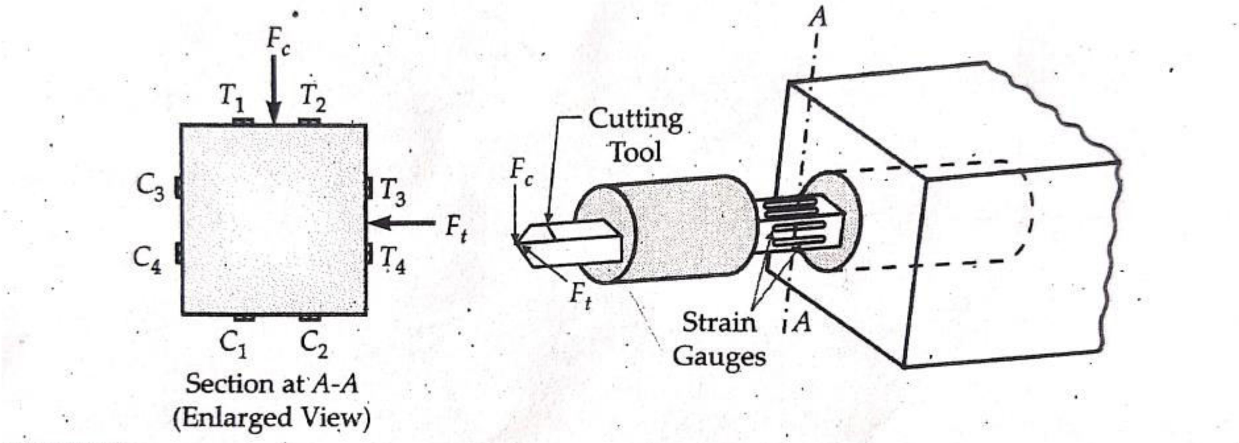
The simplest type Mechanical Dynamometer employs the use of sensitive Dial Indicators for directly measuring the tool forces. The dial indicators are calibrated to directly show the magnitude of different tool forces corresponding to the deflections caused in the tool holder due to these forces. As such, the indicators are to be fitted in the directions of the likely deflections. For example, the cutting force (Fc) will tend to deflect the tool and tool holder downwards, the Axial of Thrust force (Ft) along the axis of the work piece (opposite to the direction of the feed) and the radial force (Fr) will tend to push the tool away from work which may cause chatter. At two dimensional Dial indicator type Mechanical Dynamometer is schematically shown in figure. With this arrangement the forces Ft and Fc can be directly measured. The above principle can be easily adopted for measuring Torque and Thrust force in suitably designed Drilling Dynamometer.



Schematic of a two-dimensional dial indicator type Mechanical Dynamometer

STRAIN GAUGE TYPE DYNAMOMETERS

Strain gauges are widely used for determining the tool forces. Mechanical methods for measuring strains are not very reliable. Use of strain gauges is, therefore, taken for measuring tool forces in conjunction with Electric circuits or other means. Thus, it is an Electro-mechanical technique and the Dynamometer setup used in the process can be best described as an Electro-mechanical Dynamometer. The commonly used electric circuit is the Wheatstone bridge used in conjunction with Electrical Strain Gauges. These gauges are nothing but wound resistance wires of specific lengths which are properly encased. A simple design of a Strain Gauge Type Dynamometer, used in measurement of tool forces in turning operation on a lathe, known as Turning Dynamometer, is shown in fig. It works in conjunction with a Wheatstone flow bridge circuit, as shown. It is a set-up for two dimensional force measurement. The forces being measured are the cutting force (Fc) and the Axial or Thrust force (Ft). It is a cantilever type design, in which a substantial length of the dynamometer along with the tool projects outwards.

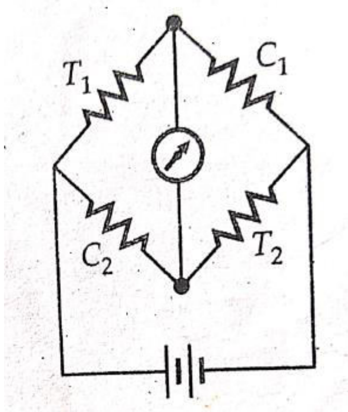


Use of Strain Gauges in a set-up for two-dimensional Force measurement in Turning on a Lathe.

The basic principle involved in this Force Measuring Technique is that the electric resistance of a wire changes when it is stretched. The wire gauges used are given the shape of a flat coil bonded between two thin sheets of insulating paper. A square sectioned machined surface is formed on the body, carrying flat surfaces is formed on the body, carrying flat surfaces, for sticking the strain gauges over there, as shown in the diagram. The strain gauges are cemented on to the four flat surfaces by means of adhesive and allowed to dry up and given a protective coating of wax.

The given set-up carries two sets of strain gauges. One set consists of a pair gauges on the top surface and other on the bottom surface and the second set consists of one pair of gauges each on the two vertical surfaces on the two sides, as shown in the enlarged view (section A-A) on the left hand side in the diagram. The gauges are so mounted that no cross-sensitivity is there. These two sets are connected one each to two separate Wheatstone bridge circuits. When the experiment is performed, the different pairs of strain gauges are subjected to tension and the compression according to the force applied on the surface on which they are mounted. In the given case, due to the force Fc, the top surface of the section is subjected to tension and, hence, the seam gauges T1 and T2. Due to the same force, the bottom surface is subjected to compression and, hence, the strain gauges C1 and C2. Similarly, due to the force Ft the strain gauges T3 and T4 are subjected to tension and C3 and C4 to compression.

The arrangement of gauges (T1,T2,C1,C2) of the first set in Wheatstone bridge circuit is shown in Fig. In the same fashion the gauges of the second set (T3,T4,C3,C4) are arranged in another Wheatstone bridge circuit. Now, the resistance of the strain gauges subjected to tension increases due to increase in their lengths. Similarly the resistance of the gauges subjected to compression decreases due to shortening of their lengths. These changes are measured by the Wheatstone bridge. With the help of standard formulae, the strains and stresses, corresponding to the changes in lengths (and, hence, resistances) in the strain gauges, can be found out, and so the corresponding forces responsible for causing these changes.



The wheatstone bridge circuit showing the arrangement of gauges of the first set

A BRIEF SURVEY OF SOME OTHER TYPES OF DYNAMOMETERS

1. **Hydraulic and Pneumatic Dynamometer**
   The Hydraulic type of Dynamometers involve the use of a Diaphragm or a Tube which converts the load(force) changes on the cutting tool into corresponding changes in oil pressure on the diaphragm or tube and the same are transmitted to a pressure gauge, which indicates the load or force being applied on the tool. A Pneumatic Dynamometer involves the use of a Flat surface (say a plate) which is brought closer to an Air Orifice through which air passes under pressure. The obstruction to the Air flow offered by this surface results in the development of Back pressure. The changes in the back pressure due to the movement of the flat surface, which moves in proportion to the tool force, are recorded and used to indicate the corresponding tool forces.

This type of Dynamometers are fairly reliable and simple. But they are bulky and their dynamic characteristics are inferior. Also, due to the leakage of fluid and chances of entry of dust into the fluid chamber their repeatability is poor.

2. Electrical Dynamometers

All the Electrical Dynamometers involve the use of Transducers, which convert the mechanical changes, such as strain or displacement, into electrical signals. These Dynamometers can be broadly classified into the following main categories :

- In which the tool Forces directly control the Electrical output. Prominent among such dynamometers are the Piezoelectric type and Magneto elastic type.
- In which the changes Electrical Signals are indirectly produced by the Tool forces by causing strains or Displacements. This category includes Capacitive pick up type Dynamometers, Strain Gauge Dynamometers and Inductive pick-up type Dynamometers.

In the Piezoelectric type dynamometers the Transducers used are Piezoelectric crystals which are highly stiff and their pick-ups are highly sensitive. These Dynamometers have a very wide range of Force measurements ranging from as low as 1 gram to as high as 1000 kg. Main disadvantages with these dynamometers are their high cost, as compared to a strain gauge type dynamometer, and high sensitivity to changes in temperatures. However, in recent past efforts have been successfully made to develop cheaper varieties of these Dynamometers by using a Piezo-electric Load cell containing an I.C. Amplifier instead of the Charge Amplifier. Magneto-elastic type Dynamometers are mostly favored for large Force measurements, such as in testing of power presses and Machine Tools.

The Capacitive pick-up type dynamometer involves the use of two plates carrying an air gap between them. As the Cutting tool is loaded the air gap between the plates changes with a corresponding variation in the capacitance of the pickup. This change in the capacitance is transformed into an electric current which can be measured.

In Inductive pick-up type Dynamometers Inductive Transducers are used for the measurement of tool forces. Several researches like Vulf, Optiz, etc., have used these transducers in different Dynamometers designed and used by them. In these dynamometers, the Mechanical deformation caused by the cutting forces results in a change in mutual inductance. Hence, the balance of the electric circuit is disturbed. The signals obtained due to change in mutual inductance chance on account of deformation are amplified and the Cutting forces determined.

The Strain-gauge type Dynamometers have already been described earlier. Dynamometers using one or the other of the above principles are also known after the process in which they are used, such as Turning Dynamometer, Drilling Dynamometer, etc. However, a detailed description of the principles, design and functions of all the different types of dynamometers available is beyond the scope of this small chapter. Hence, omitted here.

UNIT - III:

Machine tools: Introduction, classification of machine tools , generating and forming, methods of generating surfaces , basic elements of machine tools.

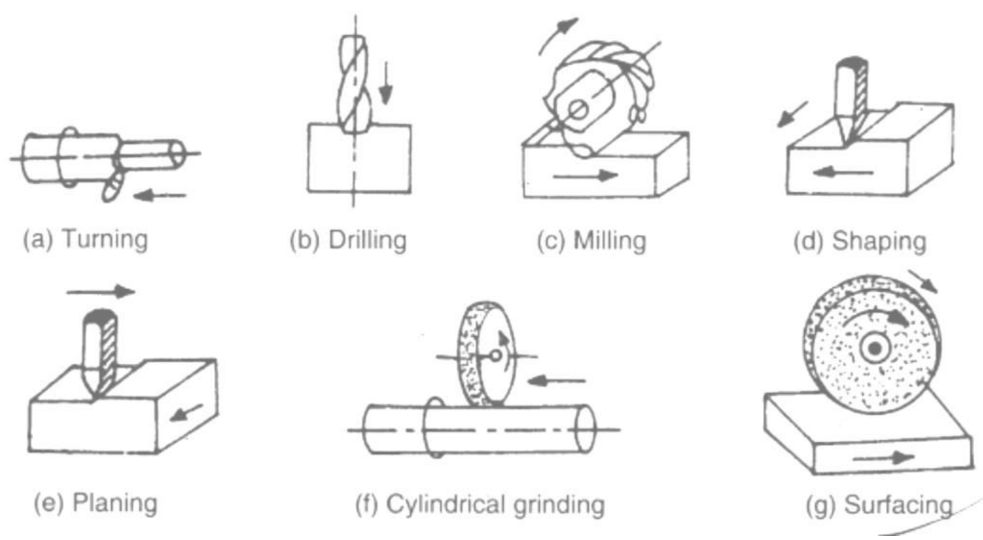
Centre lathe – constructional features ,specifications , operations , taper turning methods , thread cutting methods , tool and work holding devices , speed, feed, depth of cut , material removal rate , machining time calculations, capstan and turret lathes , difference between turret lathes and centre lathe.

Introduction

Machining is accomplished with the use of machines known as “Machine tools”. For production of variety of mahcined surfaces different types of machine tools have been developed. The kind of surface produced depends upon the shape of cutting, the path of the tool as it passes through the material or both. Depending on them metal cutting processes are called either turning or planning or boring or other operations performed by the machine tools like lithe, shaper, planer, drill, miller, grinder etc.

Definition of machine tool

A machine tool is a non-portable power operated and reasonably valued device or system of devices in which energy is expended to produce jobs of desired size, shape and surface finish by removing excess material from the preformed blanks in the form of chips with the help of cutting tools moved past the work surface(s). as illustrated schematically in Figure.



Machine tools are the kind of machines on which the metal cutting or metal forming processes are carried out. They employ cutting tools to remove excess material from the given job.

The functions of a machine tool are:

(i) To hold the tool;

(ii) To move the tool or the workpiece or both relative to each other;

(iii)To supply energy required to cause the metal cutting.

Basic functions of machine tools
Machine tools basically produce geometrical surfaces like flat, cylindrical or any contour on the preformed blanks by machining work with the help of cutting tools.
The physical functions of a machine tool in machining are:

- Firmly holding the blank and the tool.
- Transmit motions to the tool and the blank.
- Provide power to the tool-work pair for the machining action.
- Control of the machining parameters, i.e., speed, feed and depth of cut.

Classification of machine tools
Number of types of machine tools gradually increased till mid 20th century and after that started decreasing based on group technology.
However, machine tools are broadly classified as follows:
According to direction of major axis:

- Horizontal - center lathe, horizontal boring machine etc.
- Vertical - vertical lathe, vertical axis milling machine etc.
- Inclined - special (e.g. for transfer machines).

According to purpose of use:

- General purpose - e.g. center lathes, milling machines, drilling, machines etc.
- Single purpose - e.g. facing lathe, roll turning lathe etc.
- Special purpose - for mass production.

According to degree of automation:

- Non-automatic - e.g. center lathes, drilling machines etc.
- Semi-automatic - capstan lathe, turret lathe, etc.
- Automatic - e.g., single spindle automatic lathe, DNC type automatic lathe, CNC milling machine etc.

According to size:

- Heavy duty - e.g., heavy duty lathes (e.g. ≥ 55 kW), boring mills, planning machine,
- horizontal boring machine etc.
- Medium duty - e.g., lathes - 3.7 ~ 11 kW, column drilling machines, milling machines etc.
- Small duty - e.g., table top lathes, drilling machines, milling machines.
- Micro duty - e.g., micro-drilling machine etc.

According to blank type:

- Bar type (lathes).
- Chucking type (lathes).
- Housing type.

According to precision:

- Ordinary - e.g., automatic lathes.
- High precision - e.g., Swiss type automatic lathes.

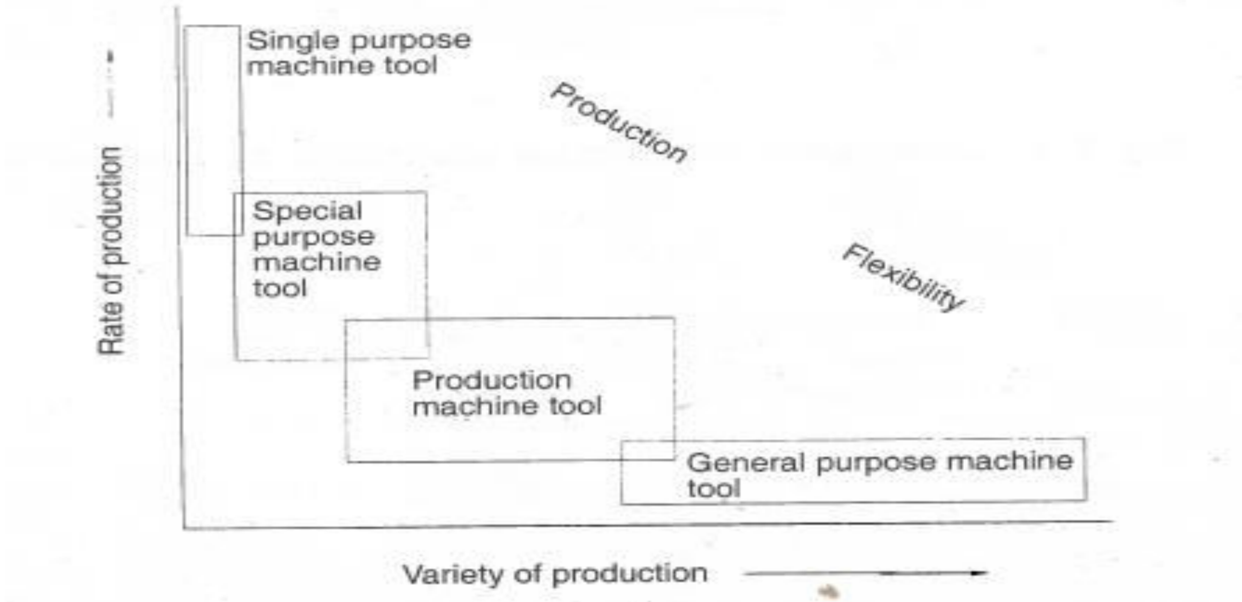
According to number of spindles:

- Single spindle - center lathes, capstan lathes, milling machines etc.
- Multi spindle - multi spindle (2 to 8) lathes, gang drilling machines etc.

According to type of automation:

- Fixed automation - e.g., single spindle and multi spindle lathes.

- Flexible automation - e.g., CNC milling machine.



Elements of machine tools

Various elements of machine tools are:

1. Structure-formed by bed, column and frame.
2. Slides and tool structure.
3. Spindles and spindle bearing.
4. Kinematics of machine tool drives.
5. Work holding, and tool holding elements.

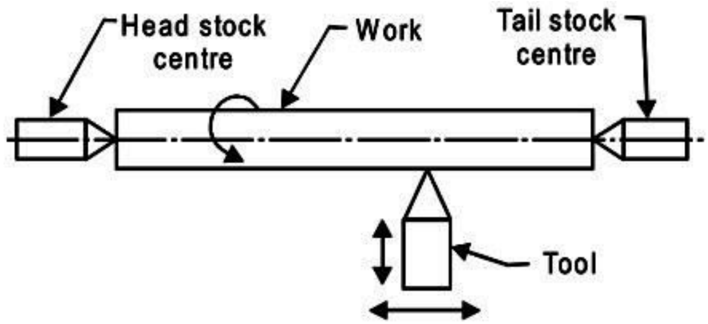
Lathe Machine

The history of invention, design and manufacture of a useful form of Lathe dates back to Eighteenth Century. Still it was in a crude form. The first useful form of Lathe, incorporating the essential features, was made by H. Maudslay, a Britisher, in 1800. Later developments and researches led to a number of amendments, as years passed, and the result is what we see today. Lathe was actually the first Machine Tool which came into being as a useful machine for metal cutting. Thus, it formed the basis of production of all the other Machine Tools which are the results of later developments.

Although we find a large number of modern Machine Tools, most of them Automatic too, still the Lathe maintains its existence as an indispensable

Machine tools even today. It still proves to be a vital necessity in all modern Tool rooms, Repair shops and Training workshops. Its main significance lies in the variety of its applications in the production of different types of jobs. As an alternative, a single job will need a number of other machine tools for performing the various operations required in its production. The utility of Lathe, even in modern advanced industry, can, therefore, be easily recognised.

Principle of Working:



- The Lathe can be defined as a Machine tool which holds the work between two rigid and strong supports, called Centres, or in a Chuck or Face plate while the latter revolves.
- The chuck or the face plate is mounted on the projected end of the machne spindle.
- The cutting tool is rigidly held and supported in a Tool post and is fed against the revolving work.
- While the work revolved about its own axis the tool is made to move eigher parallel to or at an inclination with this axis to cut the desired material.
- In doing so it produces a Cylindrical surface, if it is fed parallel to the axis or will produce a tapered surface if it is fed at an inclination.

Types of Lathe:

According to the construction and design, lathes are broadly classified as follows:

1. Bench Lathe
2. Speed Lathe
3. Engine Lathe
4. Tool Room Lathe
5. Capstone and turret Lathe
6. Automatic Lathe
7. Special – Purpose Lathe

***Bench Lathe*:**

- It is very small lathe and is mounted on a separately prepared bench or cabinet.
- It is used for small and precision work since it very accurate.
- It is usually provided with all attachments, which a larger lathe carries.
- It is capable of performing almost all the operations which a larger lathe can do.

Speed Lathe:

- These lathes may be of bench type or they may have the supporting legs cast and fitted to the bed.
- These lathes have most of the attachments which the other type of lathes carry but no provision for power feed.
- They have no gear box, carriage and lead screw.

- With the result, the tool is fed and actuated by hand.
- Usually, the tool is either mounted on a tool post or supported on a T-shaped support.
- Such lathes are usually employed for wood turning, polishing, centering and metal spinning, etc.
- They are named so because of the very high speed at which their spindle rotates

Engine Lathe:

- It is probably the most widely used type of lathe.
- It carries a great historical significance that in very early days of its development it was driven by a steam engine.
- Its *headstock* is bigger in size and more robust, incorporating suitable mechanism forproviding multiple speeds to the lathe spindle.
- The headstock spindle may receive power from a lathe shaft or an individual motor, through belts.
- It is having a cone pulley with back gears in the headstock to provide different speeds.
- It receives its power from a constant speed motor and for providing different speeds to the spindle.
- It carries a combination of gears, instead of the cone pulley and back gears combination, the lathe is known as *geared head lathe* and the headstock as *all geared headstock*.

Tool Room Lathe:

- It is nothing but the same engine lathe but equipped with *some extra attachments* to make it suitable for relatively more accurate and precision type of work carried out in a tool room.
- It carries a much wide range of speeds and feeds.
- The usual attachments provided on a tool room lathe are taper turning attachment, follower rest, collets, chucks, etc.
- This lathe is made to have a comparatively smaller bed length than the usual engine lathe.
- The most commonly used lengths are 1350 to 1800 mm.

Capstan and Turret Lathe:

- These lathe form a very important and useful group and are vastly used in mass production.
- These machines are accurately of some automatic type and very wide range of operations can be performed on them.
- In operating these machines, a very little skill is required of the operator.
- They carry special mechanisms for indexing of their tool heads.

Automatic Lathes:

- These lathes help a long way in enhancing the quality as well as the quantity of production.
- They are also designed that, all the working and job handling movements of the complete manufacturing process for a job are done automatically.
- No participation of the operator is required during the operation.

- The **semi-automatic lathes**, in which the mounting and removing of the work is done by the operator whereas all the operations are performed by the machine automatically.
- Automatic lathes are available having single or multi-spindles.
- They fall in the category of heavy duty, high speed, lathes mainly employed in mass production.

Special Purpose Lathes;

- A large number of lathes are designed to suit a definite class of work and to perform certain specified operations only.
- These are more efficient and effective than the common engine lathe so far as to specified class of work is concerned.

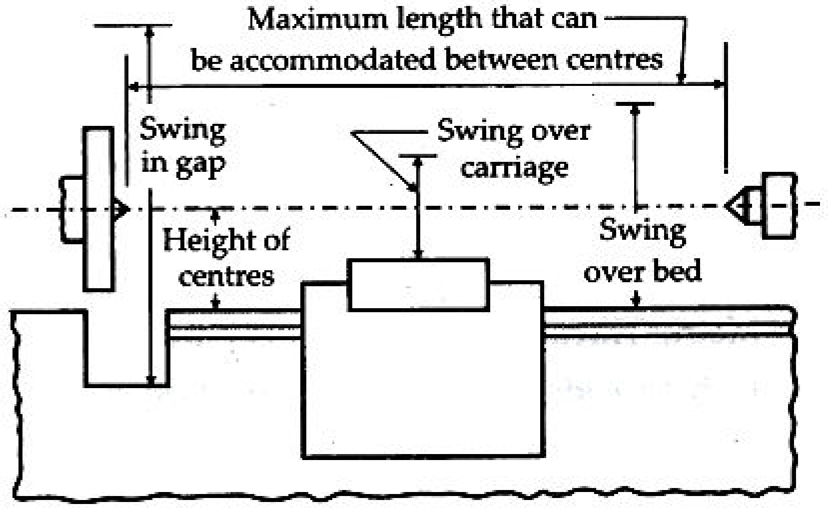
According to the height of centers

- *Small lathes* : having height of centers up to 150 mm.
- *Medium- size lathes* : having height of centers from 150 to 300mm.
  Heavy duty lathes : having height of centers above 300 mm

According to the type of drive the lathes can be grouped as

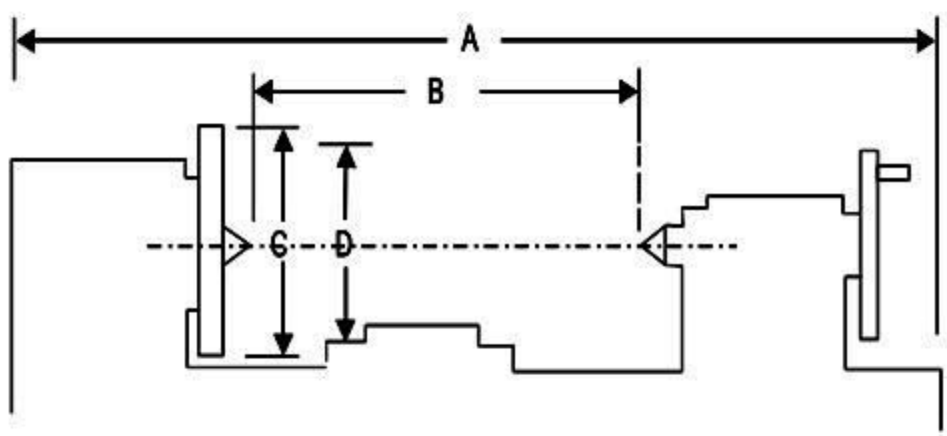
- Lathes Having **step cone pulley drive** and the **back gears** to provide various speeds to the work.
- This type of drives calls for the use of counter shaft which carries a similar cone pulley to that provided on the lathe spindle.
- This counter shaft in addition to the step pulley, carries two clutch pulleys also, which are connected to the main shaft through the belts.
- One of these pulleys carries an open belt and the other a cross belt, to rotate the machine spindle in opposite directions.
- Lathes Having **step-cone pulley drive** as usual and the **back gears** but having individual motor drives, thus eliminating the use of main shaft.
- This type of drives is conveyed from the motor to the counter shaft and then to the machine spindle.
- Lathes having **single pulley constant speed** or **geared head drive**.
- In this a single pulley is driven by means of 'V' belts by the motor and the internal mechanism of the head stock.
- It is designed to have various speed gears, enables a wide range of speeds of the spindle.
- The quick change gears provides power feed to the carriage.

Specifications of Lathe:



The size or specifications are expressed by the following items:

1. The height of the centers measured from the lathe bed.
2. The swing diameter over bed i.e., the largest diameter of work that will revolve with out touching the bed and is twice the height of the center measured from the bed of the lathe.
3. The length between centers. This is the maximum length of the work that can be mounted between the lathe centers.
4. The swing diameter over carriage. This is the largest diameter of the work that will revolve over the lathe saddle, and is always less than the swing diameter over the bed.
5. The maximum bar diameter. This is the maximum diameter the bar stock that will pass through pass through hole of the headstock spindle.
6. The length of the bed. This indicates the approximate floor space occupied by the lathe



A : length of the bed

B : length between centers

C : swing diameter over bed
D : maximum bar diameter
- height of the centers
- swing diameter over carriage

Parts of a Lathe

The lathe carries the following main parts, as illustrated by a block diagram in Figure. The main parts of a Lathe are :

- Bed
- Headstock
- Tailstock
- Carriage
- Legs
- Feed mechanism

Bed:

- The bed of a Lathe acts as the base on which the different fixed and operating parts of the Lathe are mounted.
- This facilitates the correct relative location of the fixed parts and at the same time provides ways for a well guided and controlled movement of the operating part (Carriage).
- Also it has to with-stand various forces exerted on the Cutting tool during the operation. It must, therefore, be of a very rigid and robust construction.
- Lathe beds are usually made as single piece casting of semi-steel (i.e., toughened cast iron), with the addition of small quantity of steel scrap to the cast iron during melting; the material 'Cast Iron' facilitating as easy sliding action.
- However, in case of extremely large machines, the bed may be in two or more pieces, bolted together to form the desired length.
- Bed castings are usually made to have a box section incorporating cross ribs as shown in Figure.

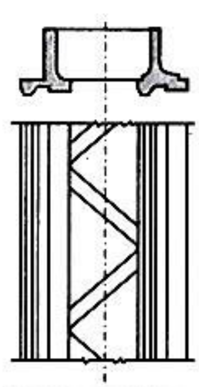
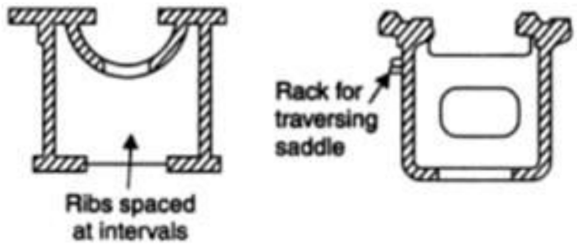


Fig. 5.4 Box type Lathe bed.

The guide ways are of two types: (a) Flat guideways (b) inverted Vee guideways. Generally, the combination of both the flat and inverted Vee guideways is used as shown below.



(a) Flat guides (b) Flat and inverted vee guides

- All-flat ways are not vbery popular now, although it is easy to produce them.
- The Prismatic, or Inverted 'V' ways are now preferred over the flat ways for the reason that their construction totally disallows the entry of chips and dirt, etc. between the saddle and the bed, thus preventing the contact surfaces from being spoined due to scratching.
- Also, they provide very efficient duiding surfaces and the wear of the bed does not have any appreciable effect on the overall alignment to the lathe.
- Most of the countries adopt a combination of the falt and prismatic shapes of bed ways. In this, the flat wyas act as supports, i.e., taking the maximum portion of the load and stresses, whereas the prismatic shapes act as guide-ways.
- Tail stock is usually guided along the bed by a combination of one prismatic and one falt way.

Headstock:

- It is permanently fastened to the innerways at the left hand end of the bed.
- It serves to support the spindle and driving arrangements.
- All lathes receive their power throught the headstock, which may be equipped with a step-cone pulleys or a gear head drive (the modern lathes are provided with all geared type head stock to get large variations of spindle speeds).
- In order to allow the long bar or work holding devices to pass through, the headstock spindle is made hollow. A tapered sleeve fits into the tapered spindle hole.

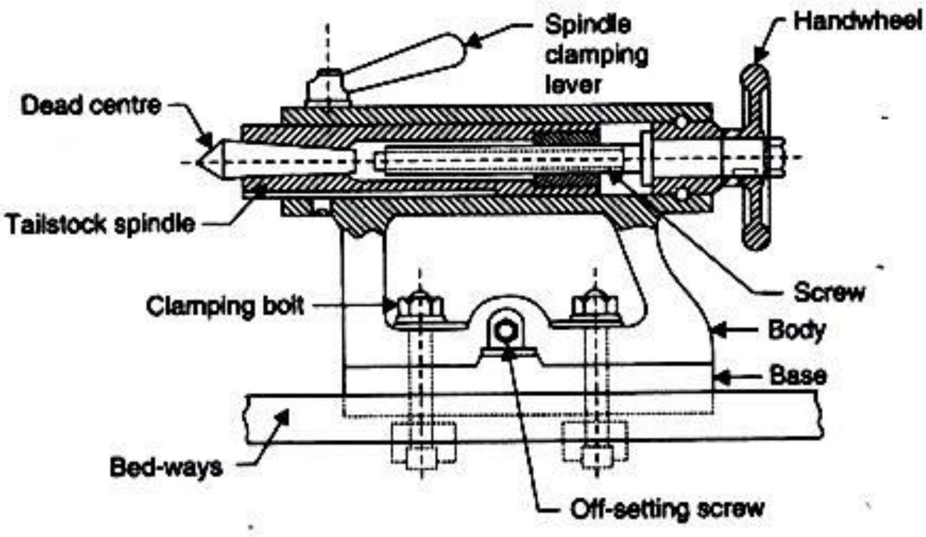
It consist of the following main parts:

1. Cone pulley
2. Backgears and backgear lever,
3. Main spindle or Head stock spindle
4. Live centre, and
5. Feed reverse lever.

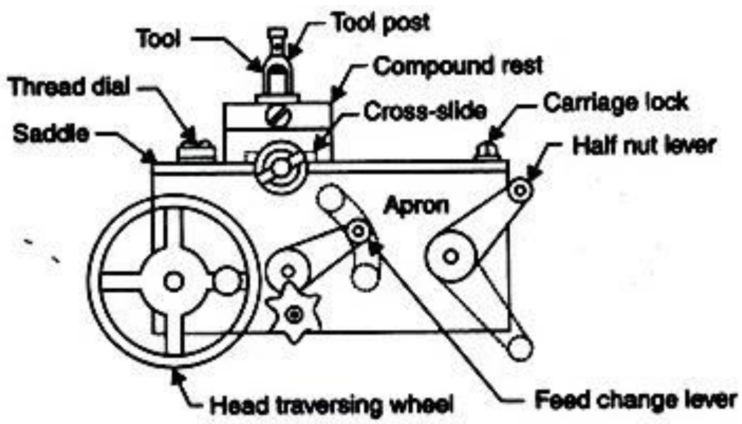
Tailstock :

It is situated at the right hand end of the bed.

- It is used for supporting the right end of the work.
- It is also used for hodling and feeding the tools such as drills, reamers, taps etc.



Carriage:



- The carriage controls and supports the cutting tool.
- The carriage has the following five major parts :

(i) Saddle. It is a H-shaped casting fitted over the bed. It moves along the guide ways.
(ii) Cross-slide. It carries the compound slide and tool post; can be moved by power or by hand.
(iii) Compound rest. It is marked in degrees; used during taper turning to set the tool for angular cuts.
(iv) Tool post. The tool is clamped on the tool post.
(v) Apron. It is attached to the saddle and hangs in front of the bed. It has gears, levers and clutches for moving the carriage with the lead screw for thread cutting.

***Feed mechanism*:**

- It is employed for imparting various feeds (longitudinal), cross and angular) to the cutting tool.
- It consists of feed reverse lever, tumbler reversing mechanism, change gears, feed gear box, quick change gear box, lead screw, fed rod, apron mechanism and hald ntu mechanism.

Lathe Accessories or Work Holding Devices and Tool Holding Devices:

The devices employed for handling and supporting the work and the tool on the lathe are called its accessories. The various accessories are enumerated below :

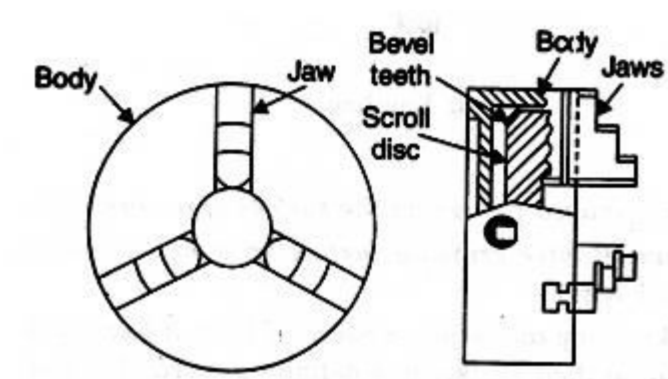
1. Chucks
2. Face plate
3. Angle plate
4. Driving plate
5. Lathe carriers or dogs
6. Lathe centres
7. Lathe mandrels
8. Rests
9. Jigs and fixures.

Chucks:

- A chuck is one of the most important devices for holding and rotating workpieces in a lathe.
- Workpiece of short length and large diameter or of irregular shape which cannot be conveniently mounted between centers are held quickly and rigidly in a chuck.
- A chuck is attached to the lathe spindle by means of bolts with the back plate or screwed on the spindle nose.
- There are different kinds of chucks:

1. Four jaw independent chuck
2. Three jaw universal chuck
3. Air or hydraulic operated chuck
4. Magnetic chucks
5. Collet chuck
6. Combination chuck
7. Drill chuck

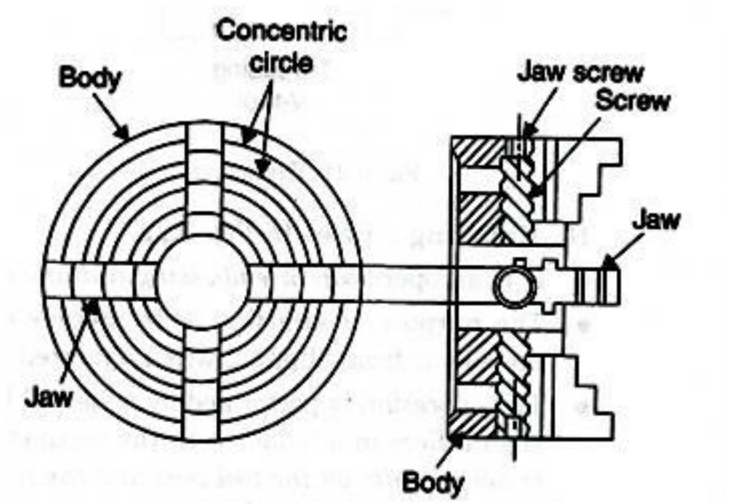
Three Jaw Self Centering Chuck:



- A three jaw chuck is used for gripping cylindrical workpieces when the machined surface is concentric with the work surfaces.
- The jaws have a series of teeth that mesh with spiral grooves on a circular plate within the chuck.

- This plate can be rotated by the key inserted in the square socket, resulting in simultaneous radial motion of the jaws.
- Since the jaws maintain an equal distance from the chuck axis, cylindrical workpieces are automatically centered when gripped.

Four jaw independent chuck:



- This chuck has four jaws which may be made to slide within the slots provided in the body of the chuck for gripping different sizes of work piece.
- Each jaw may be moved independently by rotating the screw which meshes with the teeth cut on the under side of the jaw.
- Each jaw is made of tough steel has three inner and one outer gripping surfaces.
- The outer gripping surface is used for holding larger sizes of the work piece by reversing the jaw.
- Although accurate mounting of a workpiece can be time consuming, a four-jaw chuck is often necessary for non-cylindrical workpieces.

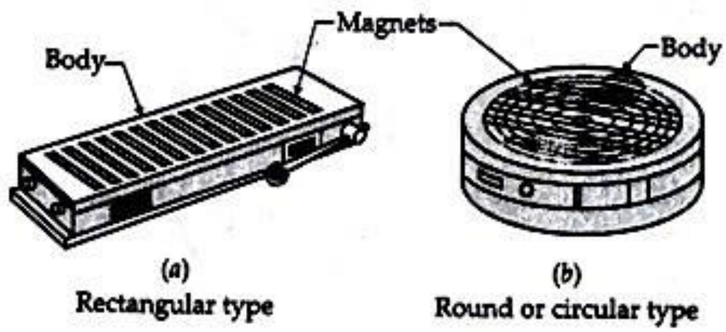
Combination Chuck:

- As the name implies, a combination chuck, may be used both as a self centering and an independent chuck to take advantage of both the types.
- The jaws may be opened individually by separate screws or simultaneously by the scroll disk.

Magnetic Chuck

- It implies the use of Electric Current for developing a strong Electromagnet which holds the job centrally in the chuck.
- Although many designs of these chucks are prevalent, still the Rotary type is in common use.
- One notable feature of this type of chuck is that it is not capable of withstanding heaby cuts on the job it grips and also that the job to be held in his chuck should be of iron or steel.

➢ They are also known as Electro-magnetic Chucks.



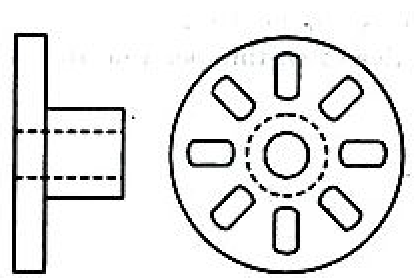
Air or Hydraulic Chuck

➢ In these chucks, Air or Hydraulic Pressure is used for pressing the jaws against the job.
➢ The pressure is provided by a cylinder and piston mechanism, fitted at the rear of the Head Stock, and is controlled by a Valve by the operator.
➢ Threes chucks are very quick acting and provide a very firm grip. Their use is, however, largely confined to those machines engaged in mass production.

Collect:

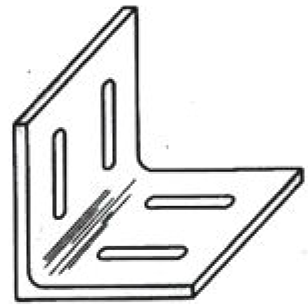
➢ It is another useful type of chuck which provides very firm grip, but ist use is confined to small jobs only.
➢ Draw-in type Collects are in common use. Their front portion is splittedf which provides a springy action and hence the grip.

Face plate:



➢ It is usually a circular cast iron disc, having a threaded hole at its centre so that it can be screwed to the threaded nose of the spindle.
➢ It consists of a number of holes and slots by means of which the work can be secured to it. A number of other things like bolts, nuts, washers, clamping plates and metallic packing pieces, etc., are required for hodling the work properly on a face plate.

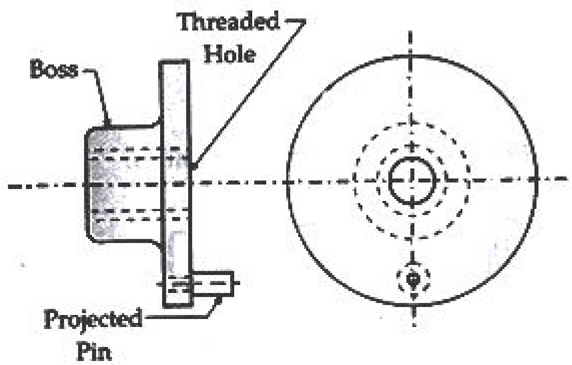
Angle Plate:



- It is employed for hodling work in conjuction with a Face plate.
- When the size or shape of the work is such that it is not possible to mount the work directly on the face plate, the Angle plate is secured to the Face plate and work mounted on it.
- It is almost an indispensable attachment for most of the operations in Face plate work.
- A useful form of Angle plate is shown in Figure.

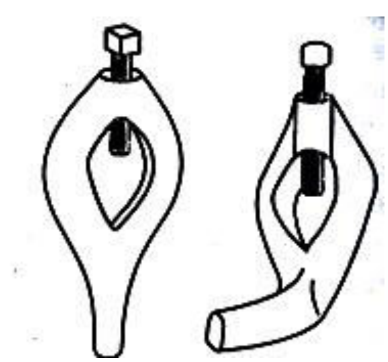
Driving Plate

- It is a cast iron circular disc having a projected Boss at its rear.
- The Boss carries internal threads, so that it can be screwed on to the spindle nose.
- It also carries a hole to accommodate a pin which engages with the tail of Lathe dog or Carrier when the job is held in the latter.



Lathe Carriers or Dogs:

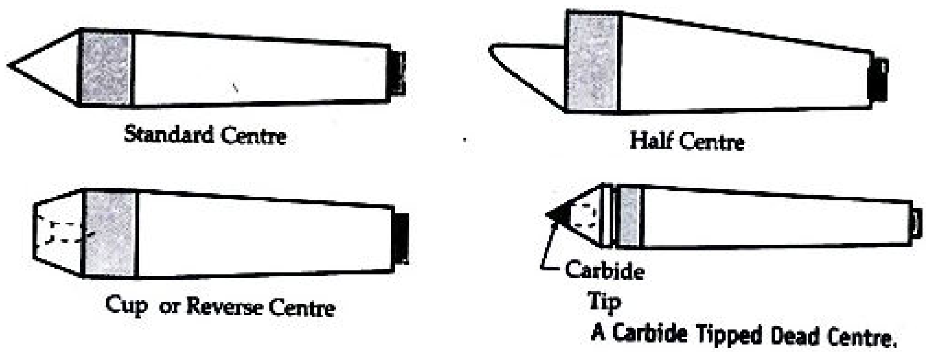
As stated above, they are used in conjuction with the Driving plate. The two common forms, known as Stright tail and Bent tail, are shown in Figure. Tthe work to be held is inserted in the 'V' shaped hole of the Carrier and them firmly secured in position by means of the set screw. It may, however, be noted that the capacity of threes carriers is limited to hold a certain range of diameters only and very big jobs are eigher held in Chucks or Face plates.



Centres:

- They form a very important group of Lathe Accessories and are made in various designs.

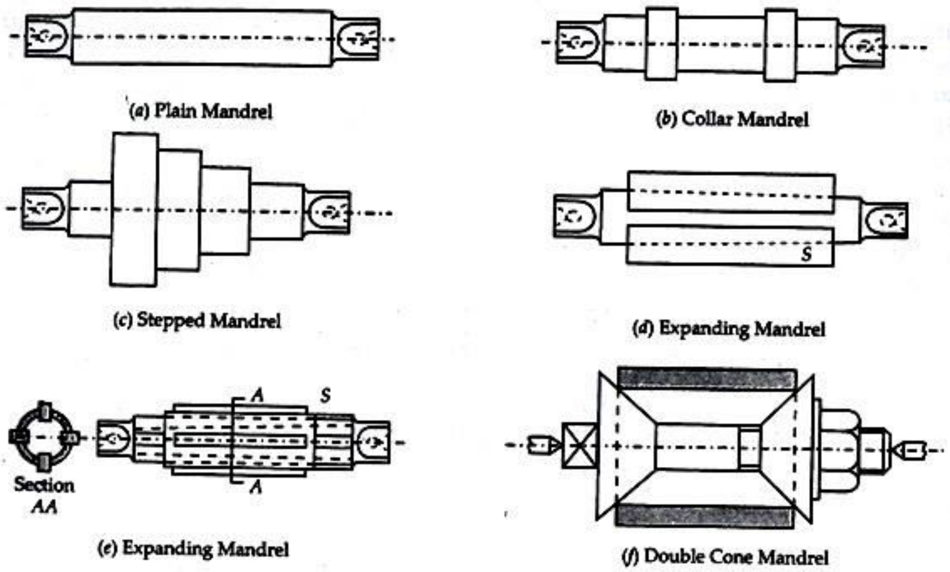
- They act as solid bearings to support the work during the operation. Cast steel or High grade tool steel is the common material used for their manufacture.
- They are then hardened and ground to correct angle. Sometimes, when very high speeds are to be employed, tips made of some other hard materials like cemetned carbide or high spped steel are used which are fitted into usual types of shanks.
- These shanks are machined to have standard taper to fit in the corresponding tapered holes in the Spindle or Tail stock sleeve. Tip of the Centre is usually made to have an included angle of 60°.



Common types of Lathe Centres.

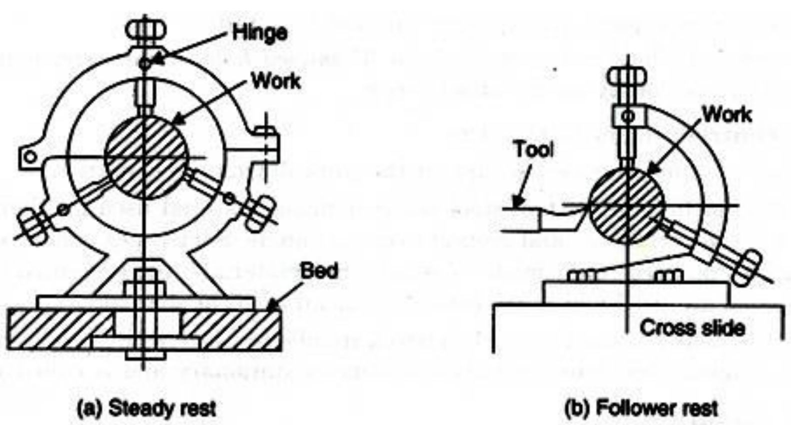
- The common forms of Dead Centres are shown in Figure.
- The ordinary type or Standard Centre is most commonly employed.
- In case of the Half centre, about half of its front cone is removed by filing to give the shape shown. Its specific use is in facing operation.
- A Cup Centre or Reverse Centre is employed ehwn a work of small diameter is to be turned which has a conical end, ie., ends in a sharp point.
- Yet another type of Dead Centre used in high speed machining is a Carbide tipped centre, shown in Figure.

Lathe mandrels :



- A “mandrel” can be described as a solid steel shaft or spindle which is used for holding bored parts for machining their outside surfaces on lathe. They are also known as arbors.
- Mandrels are usually employed for those jobs (relatively small) which have a finished hole which is concentric with the outer surface that is to be machined.
- The common types of mandrels are: Solid or plain, collar, stepped, expanding and double cone mandrels.

Rests:

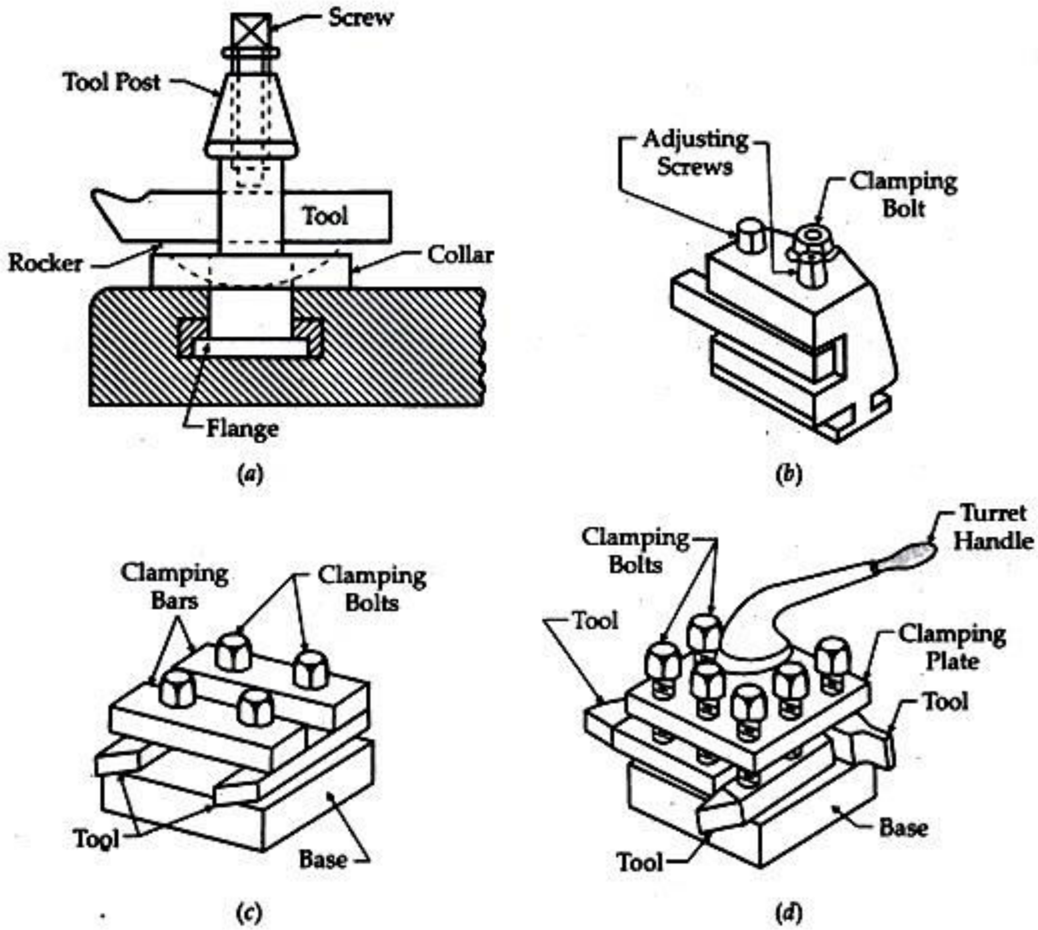


- When a very long job is to be turned between centres on a lathe, due to its own weight it provides a springing action and carries a lot of bending moment. The result is that the turning tool is spoiled very soon and may even break sometimes. To aboid this, such jobs are always supported on an attachment known as ‘steady rest or centre rest’
- Sometimes, when the job is too flexible, it becomes necessary to support the job very close to the cutting edge of the tool throughout the operation. In such cases a ‘follower rest’, is used instead of the steady rest. It is attached to the saddle of the lathe carriage and thus travels along with the tool throughout the operation.

Jigs and fixtures:

- Jigs and fixtures are used in conduction with the face plate on a lathe for supporting and holding odd shaped and eccentric jobs during the operation.
- This specific use is in the mass production of identical parts otherwise, if only a single item is to be made, the cost of production of the jigs or fixtures itself will be too high, preventing their use.

Tool holding devices:



- **Tool posts** are the devices used on various machines for holding the tools in position and providing a rigid support to them during the operation.
- Common types of Tool posts used on Lathes are shown in Figure.
- The American type single tool post shown in Figure(a) is used for holding as single Tool holder or a Solid forged tool only. It is commonly used in light work. It consists of a vertical body having a Slot to accommodate the tool shank and a Flange at its bottom. The Collar carries a spherical groove in which the Rocket is placed. This rocker can be tilted to adjust the height of the cutting edge of the tool. This adjustment wil, obviously, change the effective rake and clearance angles of the tool.

- A better form of Single tool post, called the Open side Tool post, is shown in Figure(b).
- The main Clamping bolt is used for securing the Tool post and the adjusting screws for gripping the tool in position. Height of the tool is adjusted by using flat packing pieces under the tool. This form of tool post is also used as a Rear tool post on lathes.
- Another useful form of Tool post, usually employed on heavy duty Lathes, is shown in Figure(c).
- It is provided with four bolts, each carrying a coiled spring. Two tools can be simultaneously mounted on it. The tools are held between the base and Clamping bars and gripped firmly by tightening the bolts. The Springs help in keeping the bars in position when the tools havbe been withdrawn.
- A Square tool post, vastly used in mass production, is shown in Figure(d).
- It can accommodate four tools at a time. It is also called a Turret Tool Post. It facilitates mounting of 4 different tools prior to starting the operation and bringing them to the desired position, one after the other, by rotating the handle. Such arrangement ia an asset and a vital necessity in repetition work because it saves a lot of time in tool setting.

Lathe Operations

- Operations which are performed in a lathe either by holding the work piece between centres or by a chuck are:

1. Facing	2. Turning		3. Taper turning
4. Drilling	5. Reaming		6. Boring
7. Undercutting or grooving	8. Threading	9. Knurling	10. Forming

Centering:

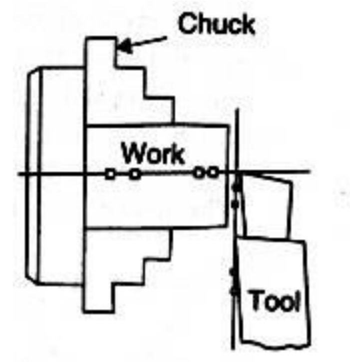
- Centering is the operation of producing conical holes in the work piece.
- Where the work is required to be turned between centres or between a chuck and a centre, conical shaped holes must be provided at the ends of the work piece to provide bearing surface for the lathe centres.
- The centre may be located by any one of the following equipments :
  - Using centre head and steel rule of a combination set.
  - Using a hermaphrodite caliper.
  - Using a divider and surface plate.
  - Using a surface gauge.
  - Using a bell center punch.

Facing:

- **Facing** is an operation of machining the ends of a workpiece to produce a flat surface square with the axis. It is also used to cut the work to the required length.
- The operation involves feeding the tool perpendicular

to the axis of rotation of the workpiece.

- A properly ground facing tool is mounted in the tool post. A regular turning tool may also be used for facing a large workpiece. The cutting edge should be set at the same height as the centre of the workpiece.

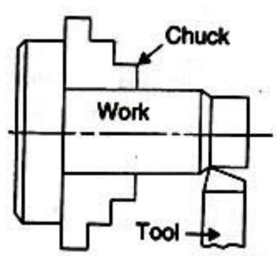


Turning

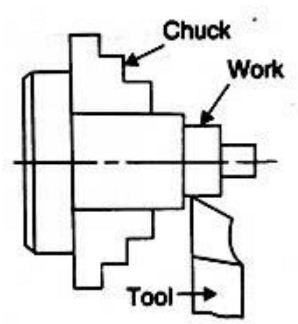
- Turning is the most commonly used operation in Lathe.
- Turning in a lathe is to remove excess material from the work piece to produce a cylindrical or a cone shaped surface.
- Normally the work piece is rotated on a spindle and the tool is fed into it radially, axially, or both ways simultaneously, to give the required surface.
- The term 'turning', in the general sense, refers to the generation of any cylindrical surface with a single point tool.
- The common types of turning are:
    - Plain turning
    - Step turning
    - rough turning
    - finish turning
    - shoulder turning and
    - taper turning.

1. Plain turning:

- It is an operation of removing excess material from the surface of the cylindrical workpiece.
- In this operation, the work is held eigher in the chuck or between centres and the longitudinal feed is given to the tool either by hand or power.

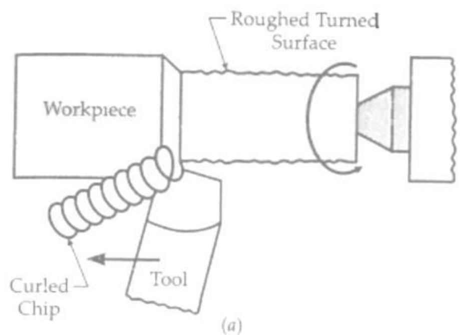


2. Step turning:



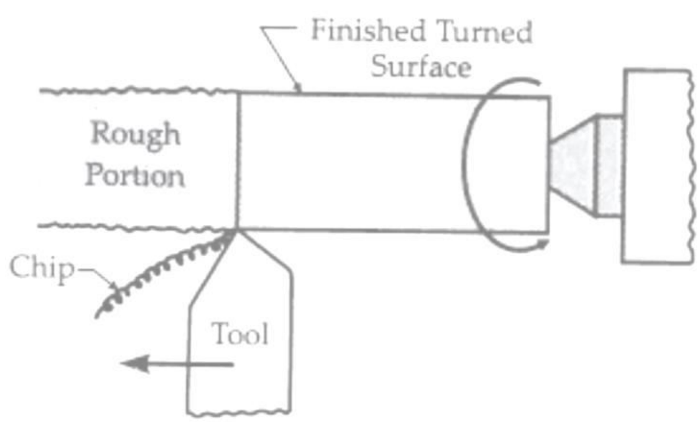
- In this type of lathe operation various steps of different diameters in the workpiece are produced.
- It is carried out in the similar way as plain turning.

3. Rough Turning:



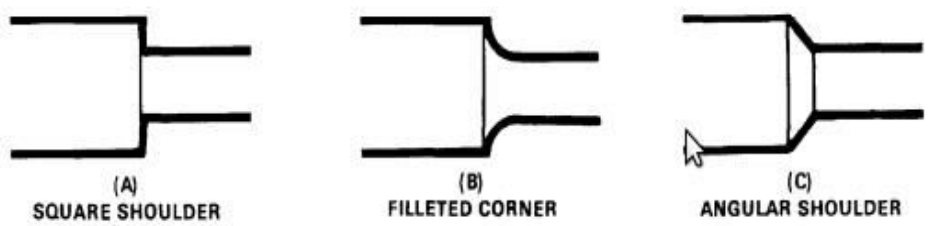
- Rough Turning is the term used for the process of heavy stock removal in order to save machining time.
- In this process, deeper cut is taken and heavier feed is employed. However, rigidity of the machine should be considered before deciding upon the feed rate and depth of cut. The surface produced will, obviously, be rough.
- A sharp edged heavy turning tool with a strong cutting dege is employed in this operation so that it is strong enough to take deep cuts and is capable of bearing the heavy cutting forces.

4. Finish Turning:



- Once the larger part of the excess material has been removed through Rough Turning, it is followed by Finish Turning Operation in order to bring the job to correct size and provide a fine surface finish on it.
- The amount of excess material to be removed through this operation is very less and therefore, lighter feed and smaller depth of cut are used the heavier tool is replaced by a finish turning tool.

5. Shoulder Turning:

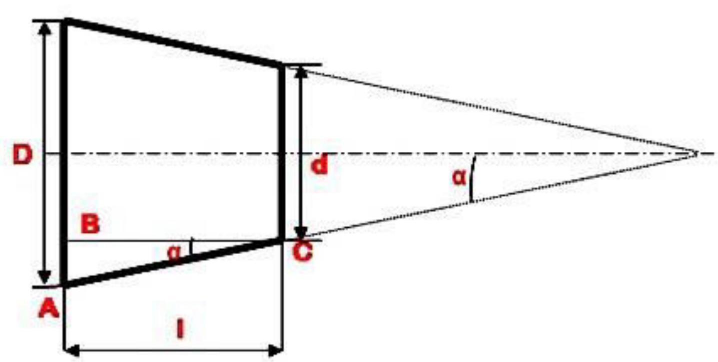


- Shoulder is that part of a component where its two different diameters meet each other, forming a step.
- This can have several forms, such as square, bevelled, undercut or having a radius.
- The first three are automatically formed while turning the smaller diameter, if a tool of properly shaped cutting edge is used.
- The undercut shoulder can be formed by feeding a parting tool into the larger diameter closer and parallel to the surface of the smaller diameter.

6. Taper Turning:

- A taper may be defined as a uniform increase or decrease in diameter of a work piece measured along its length.

Taper Elements:



Where, D = Large diameter of taper in mm.
d = small diameter of taper in mm.
l = length of taper part in mm
2α = full taper angle
α = angle of taper angle or half taper angle.

Refer to Figure, The taper angle α can be found by using the following relationship :

$$Tan \ \propto = \frac{D-d}{2L}$$

or,

$$\propto = \tan^{-1}\left(\frac{D-d}{2L}\right)$$

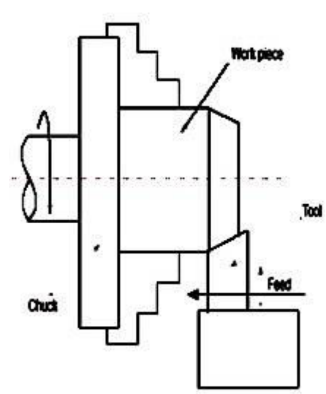
- The amount of taper or conicity of taper in a work piece is specified by ratio of the difference in diameters of the taper to its length. This is termed as conicity and designated by letter K.

The conicity K of a taper is defined as:

$K\ (= 2\tan \propto) = \frac{D-d}{L}$

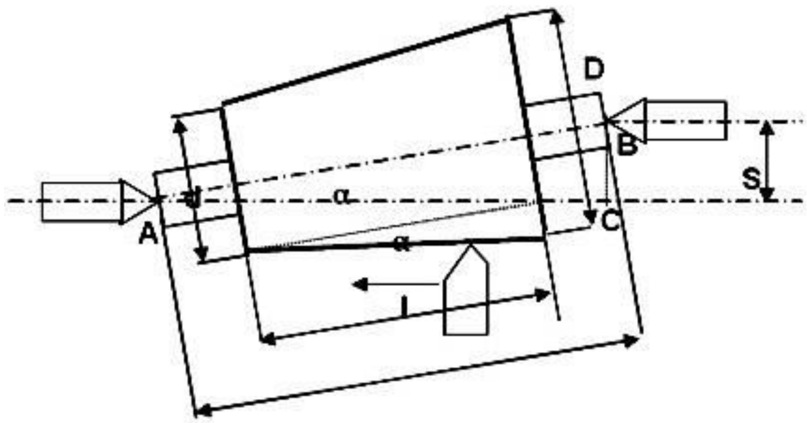
- In a Lathe taper turning is an operation to produce a conical surface by gradual reduction in diameter from a cylindrical job.
- Taper turning can be done by the following ways:
  1. By a form tool.
  2. By setting over the tailstock.
  3. By swiveling the compound rest.
  4. By taper turning attachment.
  5. By compound feed.

Taper Turning by a Form Tool:



- Taper turning by a form tool uses a tool which is a broad nose tool having straight cutting edge.
- The tool is set on the work piece at half taper angle, and is fed straight into the work to generate a tapered angle.
- This method is limited to turn limited length taper only.
- This is due to the reason that the metal is removed by entire cutting edge, and any increase in length of the taper will necessitate the use of a wider cutting edge.
- This will require excessive cutting pressure, which may distort the work due to vibration and spoil the work due to vibration and spoil the work surface.

By Setting Over the Tailstock:



- The principle of turning taper by this method is to shift the axis of rotation of the workpiece, at an angle to the lathe axis, and feeding the tool parallel to the lathe axis.
- The angle at which axis of rotation of the workpiece is shifted is equal to half angle of taper.
- The amount of setover is limited. This method is suitable for turning small taper on long jobs.
- The main disadvantage of this method is that the live and dead centres are not equally stressed and the wear is not uniform. Moreover, the lathe dog being set at an angle, the angular velocity is not constant.

From geometry:

BC= Setover

BC=AB sin α

Setover = L sin α

If the angle α, the angle of taper, is very small, for all practical purposes,

Sin α=tan α

⇨ Setover = L tan α

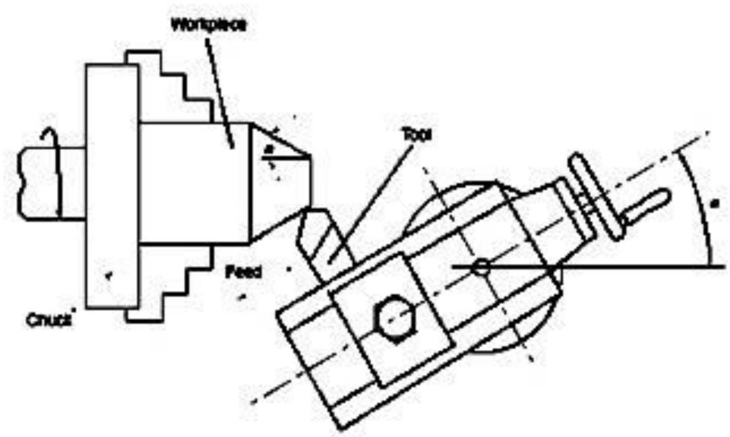
⇨ Setover = $L\frac{D-d}{2l}$

⇨ Setover = $\frac{entire\ length\ of\ the\ work\ X\ conicity}{2}$

If the taper is turned on the entire length of the workpiece, then 1 = L

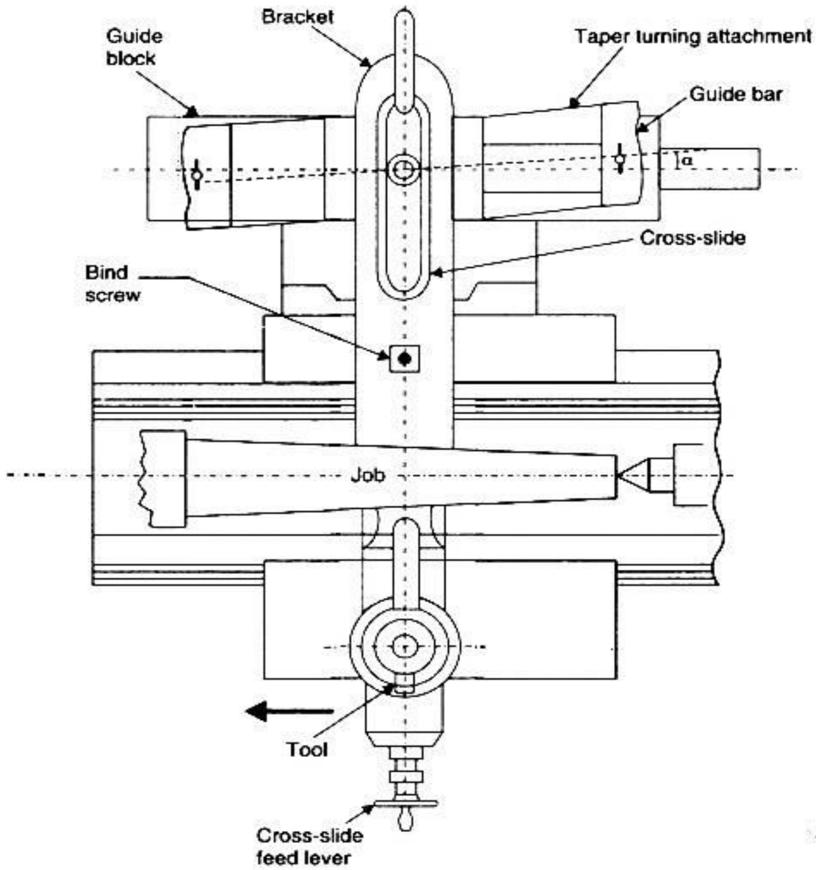
Setover = $\frac{D-d}{2}$

***By Swiveling the Compound Rest*:**



- This method employs the principle of taper turning by rotating the workpiece on the lathe axis and feeding the tool at an angle to the axis of rotation of the workpiece.
- The tool is mounted on the compound rest, is attached to a circular base, graduated in degrees, which may be swiveled and clamped at any desired angle.
- Once the compound rest is set at the desired half taper angle, rotation of the compound slide will cause the tool to be fed at an angle and generate the corresponding taper.
- This method is limited to turn a short but steep taper owing to limited movement of the cross slide.
- The movement of the tool in this method is controlled by hand, thus this gives low production rate and poor surface capacity.

By Taper Turning Attachment:



- The principle of taper turning by taper turning attachment is to guide the tool in a straight path set at an angle to the axis of rotation of the workpiece, while the work is being held by a chuck or between centres aligned to the lathe axis.
- A taper turning attachment consists of a frame or bracket which is attached to the rear end of the lathe bed and supports a guide bar pivoted at the centre.
- The bar having graduations in degrees may be swiveled on either side of the zero graduation and is set at any desired angle with the lathe axis.
- When taper turning attachment is used, the cross slide is first made free from the lead screw by removing the binder screw.
- The rear end of the cross slide is tightened with the guide block by means of bolt.
- When longitudinal feed is engaged, the tool mounted on the cross slide will follow the angular path, as the guide block will slide on the guide bar set at an angle to the lathe axis.
- Taper turning by this method does not disturb the alignment of the live and dead centre.
- By this process both steep and small taper can be made over any length of the work piece.

Advantages of using a taper turning attachment are :

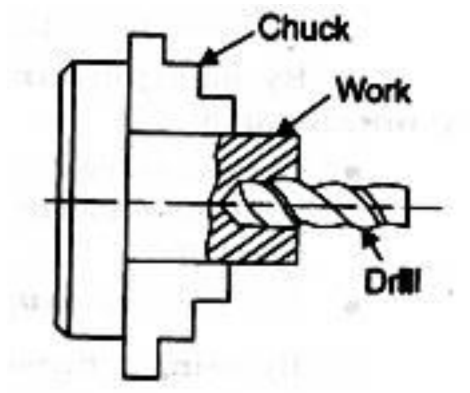
1. The alignment of live and dead centres being not disturbed; both straight and taper turning may be performed on a work piece in one setting.
2. Once the taper is set, any length of a piece of work may be turned taper within its limit.

3. Very steep taper on a long work piece may be turned, which cannot be done on any other method.
4. Accurate taper on large number of work pieces may be turned.
5. Internal tapers can be turned with ease.

By Compound Feed:

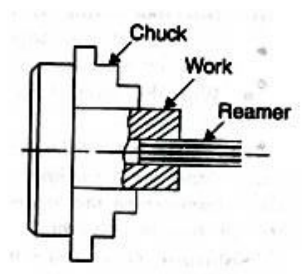
- Taper turning by manipulation of both feeds is inaccurate and requires skill on the part of the operator.
- It is used for sharp tapers only.

Drilling:



- It is an operation of producing a cylindrical hole in a workpiece by the rotating cutting edge of a cutter known as the drill.
- For this operation, the work is held in a suitable device, such as chuck or face plate, as usual, and the drill is held in the sleeve or barrel of the tailstock. The drill is fed by hand by rotating the handwheel of the tailstock.

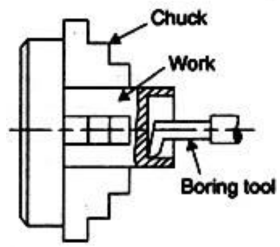
Reaming:



- Reaming is the operation which usually follows the earlier operation of drilling and boring in case of those holes in which a very high grade of surface finish and dimensional accuracy is needed.
- The tool used is called the reamer, which has multiple cutting edges. The reamer is is held on the tailstock spindle, either direct or through a drill chuck and is held stationary while the work is revolved at very slow speed. The feed varies from 0.5 to 2 mm per revolution.

- For reaming tapered holes, taper reamers are used.

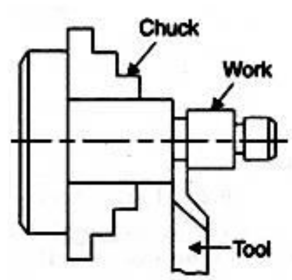
Boring:



- It is the operation of enlarging and turning a hole produced by drilling, punching, casting or forging.
- In this operation, as shown in Figure, a boring tool or a bit mounted on a rigid bar is held in the tool post and fed into the work by hand or power in the similar way as for turning.
- Boring cannot originate a hole.

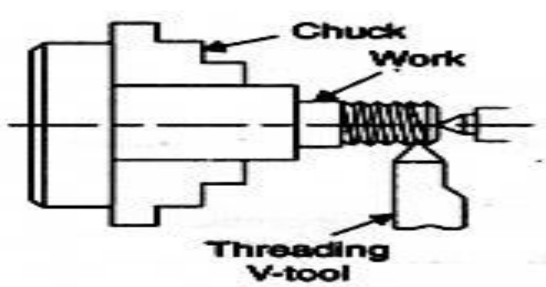
Undercutting/grooving:

- It is the process of reducing the diameter of a workpiece over a very narrow surface. It is often done at the end of a thread or adjacent to a shoulder to leave a small margin.
- The work is revolved at half the speed of turning and a grooving tool of required shape is fed straight into the work by rotating the cross-slide screw.



Threading:

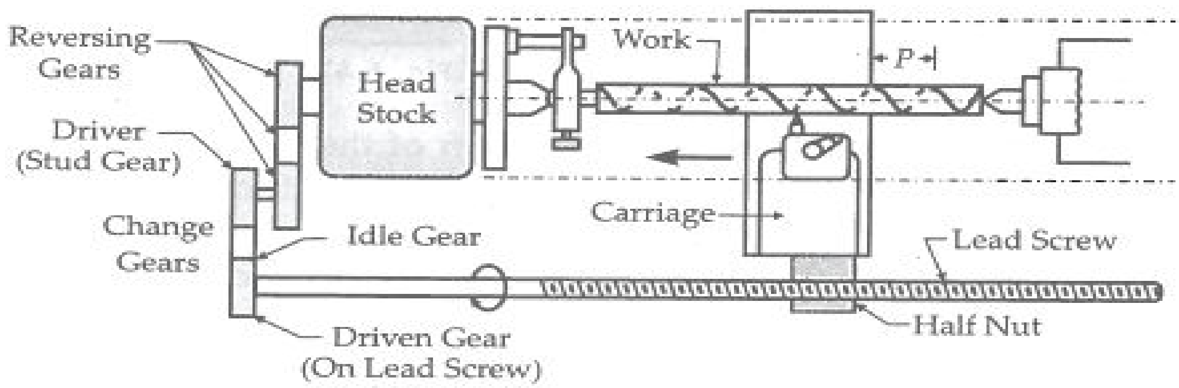
- Threading is an operation of cutting helical grooves on the external cylindrical surface of the workpiece.
- In this operation, as shown in Fig.9.21, the work is held in a chuck or between centres and the threading tool is fed longitudinally to the revolving work. The longitudinal feed is equal in the pitch of the thread to be cut.



THREAD CUTTING METHODS

Thread cutting is one of the most important operations performed in a centre lathe. It is possible to cut both external and internal threads with the help of threading tools. There are a large number of thread forms that can be machined in a centre lathe such as Whitworth, ACME, ISO metric, etc. The principle of thread cutting is to produce a helical groove on a cylindrical or conical surface by feeding the tool longitudinally when the job is revolved between centers or by a chuck (for external threads) and by a chuck (for internal threads). The longitudinal feed should be equal to the pitch of the thread to be cut per revolution of the workpiece.

The lead screw of the lathe has a definite pitch. The saddle receives its traversing motion through the lead screw. Therefore a definite ratio between the longitudinal feed and rotation of the headstock spindle should be found out so that the relative speeds of rotation of the work and the lead screw will result in the cutting of a thread of the desired pitch. This is effect by change gears arranged between the spindle and the lead screw or by the change gear mechanism or feed gear box used in a modern lathe. Thread cutting on a centre lathe is a slow process, but it is the only process of producing square threads, as other methods develop interference on the helix. *Fig. illustrates the principle of thread cutting.*

- 

Change gear ratio

Centre lathes are equipped with a set of change gears. A typical set contains the following change gears with number of teeth: 20, 25, 30, 35, 40, 45, 50, 55, 60, 65, 70, 75, 80, 85, 90, 95, 100, 110, 120, 125 and 127. The change gear ratio (*icg*) must be transformed by multiplying numerator and denominator by a suitable number, to obtain gears available in the change gear set.

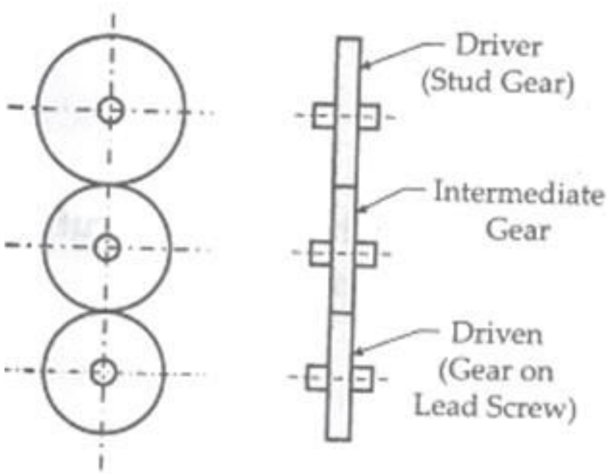
The change gear ratio may result either in a ‘Simple gear train’ or ‘Compound gear train’. In modern lathes using quick change gears, the correct gear ratio for cutting a particular thread is quickly obtained by simply shifting the levers in different positions which are given in the charts or instruction plates supplied with the machine.

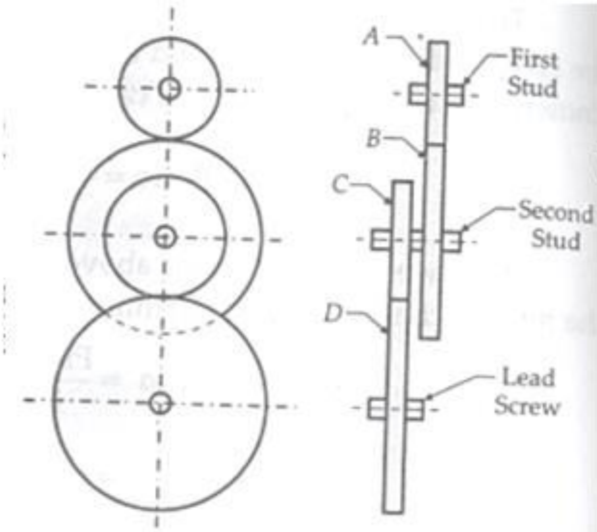
Calculation for change gear ratio

Metric thread on Metric lead screw

Calculation for change gear ratio for cutting metric thread on a centre lathe with a metric lead screw is as follows;

$$\frac{\textbf{Driver teeth}}{\textbf{Driven teeth}} = \frac{\textbf{Lead screw turn}}{\textbf{Spindle turn}} = \frac{\textbf{Pitch of the thread to be cut}}{\textbf{Pitch of the lead screw}}$$





Metric thread on British or English standard lead screw

Calculation for change gear ratio for cutting metric thread on a centre lathe with a British or English standard lead screw may be carried out by introducing a translating gear of 127 teeth. If the lead screw has *n* threads per inch and the thread to be cut has *p* mm pitch then;

$$\frac{\textbf{Driver teeth}}{\textbf{Driven teeth}} = \frac{\textbf{Pitch of the thread to be cut}}{\textbf{Pitch of the lead screw}} = \frac{p}{1/n} = \frac{p\,n}{25.4} = \frac{p\,n}{25.4 \times 5/5} = \frac{5\,p\,n}{127}$$

$$\text{Since pitch} = \frac{1}{\textbf{number of threads per inch}} \qquad \text{and 1 inch} = 25.4 \text{ mm}$$

Thread cutting procedure

1. The work piece should be rotated in anticlockwise direction when viewed from the tail stock end.
2. The excess material is removed from the workpiece to make its diameter equal to the major diameter of the screw thread to be generated.
3. Change gears of correct size are fitted to the end of the bed between the spindle and the lead screw.
4. The thread cutting tool is selected such that the shape or form of the cutting edge is of the same form as the thread to be generated. In a metric thread, the included angle of the cutting edge should be ground exactly 600.
5. A thread tool gauge or a centre gauge is used against the turned surface of the workpiece to check the form of the cutting edge so that each face may be equally inclined to the centre line of the workpiece.

6. Then the tool is mounted in the tool post such that the top of the tool nose is horizontal and is in line with the axis of rotation of the workpiece.
7. The speed of the spindle is reduced by ½ to ¼ of the speed required for turning according to the type of material being machined.
8. The tool is fed inward until it first scratches the surface of the workpiece. The graduated dial on the cross slide is noted or set to zero. Then the split nut or half nut is engaged and the tool moves along helical path over the desired length.
9. At the end of tool travel, it is quickly withdrawn by means of cross slide. The split nut is disengaged and the carriage is returned to the starting position, for the next cut. These successive cuts are continued until the thread reaches its desired depth (checked on the dial of cross slide).
10. For cutting left hand threads the carriage is moved from left to right (i.e. towards tail stock) and for cutting right hand threads it is moved from right to left (i.e. towards headstock).

Thread chaser A chaser is a multipoint threading tool having the same form and pitch of the thread to be chased. *An external thread chaser is shown in Fig. (a).* A chaser is used to finish a partly cut thread to the size and shape required. *Fig. (b) shows finishing of a partly cut thread by a thread chaser.* Thread chasing is done at about ½ of the speed of turning.

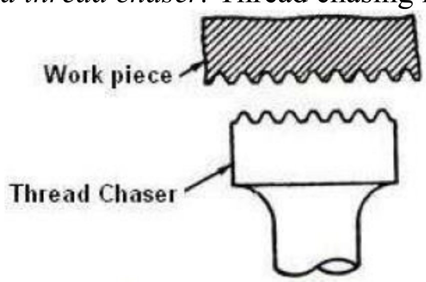


Fig. (a) External thread chaser

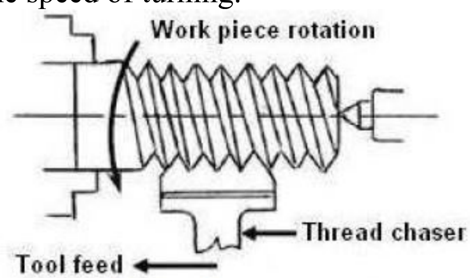
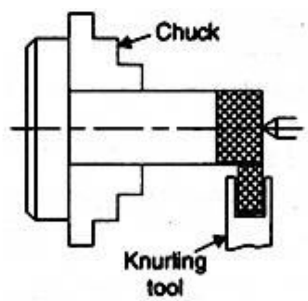


Fig. (b) Finishing of a partly cut thread

Knurling:

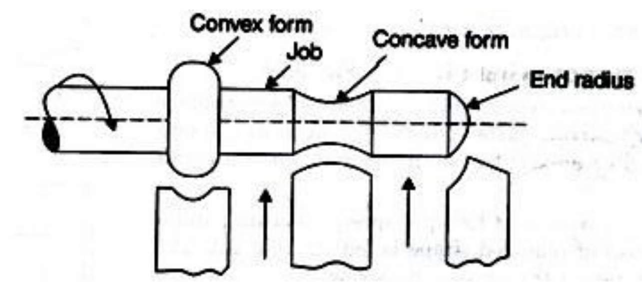


- It is an operation of embossing a diamond shaped pattern on the surface of a workpiece.
- The purpose of knurling is to provide an effective gripping surface on a workpiece to prevent it from slipping when operated by hand.
- The operation is performed by a special knurling tool which consists of 1 set of hardened steel rollers in a holder with the teeth cut on their surface in a definite pattern. The tool is held rigidly on the tool post and the rollers are pressed against the revolving workpiece to squeeze the metal against the multiple cutting edges, producing depressions in a regular pattern on the surface of the workpiece.

- Knurling is done at the slowest speed available in a lathe. Usually the speed is reduced to ¼th of that of turning, and plenty of oil is flowed on the tool and workpiece.

Forming:

- It is an operation of turning a convex, concave or any irregular shape.
- Form-turning may be accomplished by the following methods: (i) Using a forming tool, (ii) Combining cross and longitudinal feed, (iii) Tracing or copying a template.



Speed, Feed and Depth of Cut

- **Cutting speed** of the tool is directly proportional to the Surface or Peripheral speed of the work.
- It is the distance travelled per minute by a point on the circumference of the work in a direction parallel to the direction of the feed of the tool. It is expressed in meters per minute and is given by the formula.

$$V = \frac{\pi DN}{1000} mpm.$$

Where V= Cutting speed in meters per minute
D= Diameter of the work surface in mm.
and N= Speed of the work in rpm.

- The Cutting speed to be employed for a particular work depends upon a number of factors.
- The main factors which influence the selection of a proper cutting speed are the following:
  - Material of the cutting tool.
  - Hardness and machinability of the metal to be machined.
  - Quality of heat treatment, if it is a H.S.S. steel tool.
  - Whether machining is to be done with or without the use of a coolant.
  - Rigidly of the tool and the work.
  - Shape of the tool.
  - Depth of cut.
  - Feed to be given to the tool.
  - Rigidly of the machine.

Feed of the tool, which denotes the advancement of the tool for each revolution of the work. The tool can be moved in three directions with respect to the axis of the work and the corresponding feeds are named after these directions of the tool movement as described below.

1. Longitudinal Feed: Tool moves parallel to the axis of the work; such as in Plain turning, Step turning, Threading, etc.
2. Cross Feed: Tool moves normal to the axis of the work; such as in Facing, Undercutting, Parting off, etc.
3. Angular Feed: Tool moves at an inclination to the axis of the work; such as in Taper turning.

- When a job is turned on lathe, a certain amount of material is removed continuously by the tool, in a cut, in the form of chips.
- The total thickness of the material to be removed depends upon the amount of machining allowance provided on the job and the final dimensions required.
- Thickness of the metal removed in a cut by the tool is known as **Depth of cut**. In other words, 'depth of cut' as the distance, measured normal to the work axis, by which the point of the tool penetrates into the job surface in a cut. It will, obviously, be equal to half the difference of two diameters of the job. It will be expressed thus :

$$t = \frac{D-d}{2} mm.$$

Estimating Machine Time

The Total Time required in completing a job by machining will include many factors- such as actual time taken in machining (cutting time), time required in setting of job, time required in setting of tool or tools and Handling time, etc. The method of computing the actual machining or cutting time is given below.

Suppose the work is to be turned through a length of l mm,

l_1 = Distance required for feeding the tool cross-wise, to increase the depth of cut, in mm

l_2 = Over travel of the tool in mm at the end of each cut.

t = Depth of cut in mm. f_1 = Feed in mm per revolution.

N = Speed in rpm of the work.

n = Total number of cuts taken for obtaining the required diameter or the number of passes.

L_1 = Total distance, in mm that the tool travels in the direction of the feed.

Now, the Distance travelled by the tool in the direction of the feed in a single cut,

$= l+l_1+l_2 = L$ (say)

Therefore, the total distance L_1 is given by : $L_1 = L\times n$ mm

Also the amount of feed (f) per minute will be given by $f = f_1\times N$ mm

The time T, in minutes, required for the tool to move through the complete length L_1 mm will be computed by the formula: $T = \frac{L_1}{f}\ minutes \quad = \frac{L\times n}{f_1\times N}\ minutes$

Capstan and Turret Lathes

- Although centre/engine lathe is very useful and versatile yet it is not suitable for batch and mass production since the time taken for changing and setting the tools and time required for making measurements on the workpiece is quite large.
- Moreover, a skilled machinist is required to run to the centre lathe.

- This increased rate of production can be obtained by saving the time lost in changing and setting of tools for new operations.
- In other words, we can say that if the required quantity of production of identical parts can be obtained throught a single setting of tools the rate of production of these items will be quicker and economical.
- The above rate can be further enhanced by the application of more than one tool simultaneously.
- This demand of increased production is fulfilled by the use of Capstan and Turret lathes, which provide both these facilities.
- That is, the complete job can be finished in a single setting of tools and more than one tool can be employed simultaneously.
- When the operations are repeated several times with the same setting, the desired results are easily obtained.

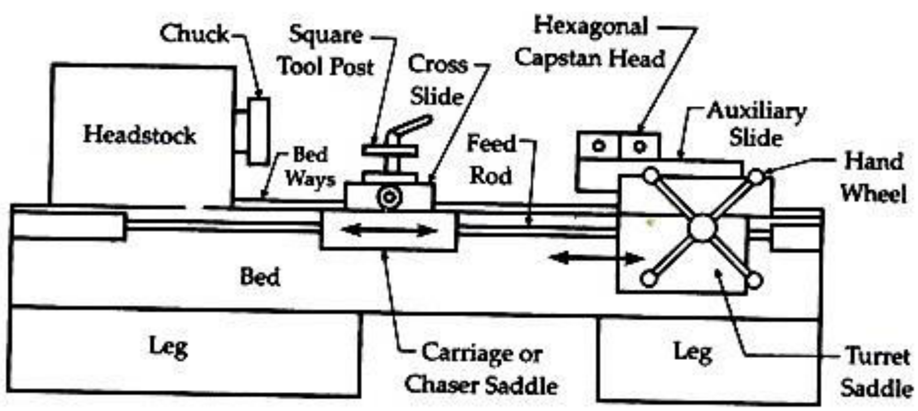
Difference between Turret Lathe and Centre Lathe:

S.No	Aspects	Turret lathe	Centre lathe
1	Nature of production work	Adapted to quantity production work; classed as a production machine tool.	Primarily used for miscellaneous jobbing, tool room or single operation work.
2	Constructional difference (Turret head or tailstock)	Hexagonal turret tailstock), upon which are bolted various tool holders for knew turning, roller box turning, drill and recessing.	It has a tailstock
3	No. of tools that can be handled at a time	Can hold a number of cutting tools at a time; the tools can operate on the job simultaneously.	One tool cuts at a time.
4	Set-up of tools	Tools may be permanently set-up in the turret in the sequence in which they need be used.	No such provision is available in a centre lathe.
5	Provision of rigidity in the holding of work and tools	Extreme rigidity to permit multiple and combined cuts.	No special provision available.
6	Machining time and handling time	Use of turret lathe can often cut machining time by 25 to 75% and handling time by 25% to 50%.	Consumes more time comparatively.

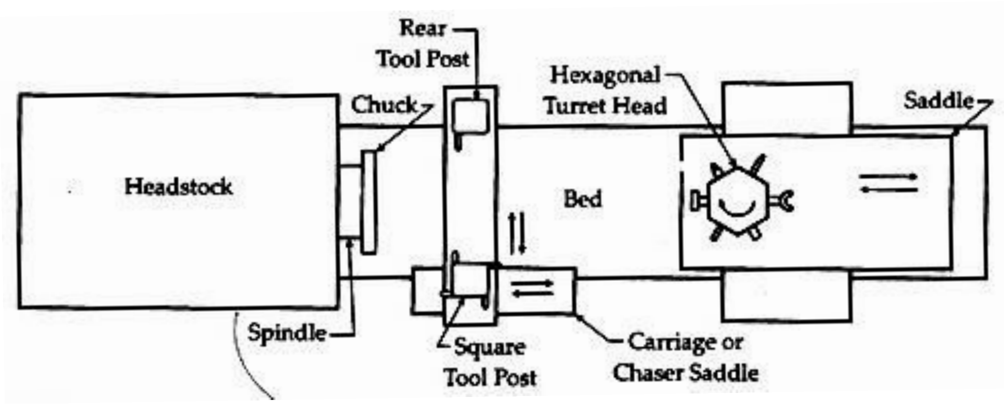
7	Lead screw	Thread cutting is generally performed by tops and die heads. Hence no lead screw is provided for thread cutting.	Always provided on a centre lathe to enable thread cutting by a single point tool.
8	Degree of automation	Semi-automatic	Very normal
9	Rate of production	Higher	Lower.
10	Labour cost	Lower, because after tools and machine setting the operations can be performed by unskilled or semi-skilled operators only.	Higher, because of the requirement of highly skilled workers.
11	Overhead charges	Higher than the centre lathe because of higher initial investment, more consumption of power and higher maintenance cost.	Lower comparatively.

Main Parts of a Turret or Capstan Lathe

The main operating parts of a Capstan and a Turret lathe are illustrated in block diagrams. The former presents the front and the latter top view.



Main Parts of a Capstan Lathe



Main Parts of Turret Lathe

***The main parts are*:**

- Headstock
- Turret saddle
- Legs
- Carriage or chaser saddle
- Bed

1. Headstock

- A turret or Capstan lathe carries a similar type of head stock as a centre lathe, but is comparatively larger in size and heavier in construction in order to provide a wider range of speeds (between 30 to 2000 rpm).
- The Headstock, as usual, carries a hollow spindle with screwed nose to accommodate the chuck. Alternatively, the spindle may have a flange at its front for holding the chuck.

The following types of headstocks are commonly used :

(i) Cone pulley type
(ii) Direct motor driven headstock
(iii) All geared headstock
(iv) Preoptive type headstock.

- One of the chief characteristics of turret headstock is the provision for rapid stopping, starting and speed changing in order that the maximum advantage is taken by the operator of the most advantageous cutting speed for any job and at the same time to minimize the loss of time in speed changing, stopping and starting.

2. Carriage or chaser saddle.

- It carries a cross-slide over it, on which are mounted two tool posts, one at the front and the other at the rear.
- Both these tool posts are usually square tool posts in which each is capable of holding four tools at a time. Tools in the rear tool post are mounted in an inverted position.

- Both hand and power feed can be employed to the saddle as well as the cross-slide, but the common practice is to use hand feed for the cross-slide until and unless a very heavy job is to be machined.
- When power feeds are in operation, stops and trip dogs are used for controlling the longitudinal and cross feeds of the saddle and cross-slide respectively. These stops and trip dogs make the power feed to disengage as soon as the required tool travel is complete.

The cross-slide carriage is of following two types;

(i) *Reach over (or bridge) type*: Its construction is more rigid and allows a second tool holder to be mounted at the rear.

(ii) *Slide hung type*: This type of carriage is generally fitted with heavy duty turret lathe where the saddle rides on the top and bottom guideways on the front of the lathe bed.

3. Turret saddle.

- It is mounted directly on the lathe bed on the same side as a tailstock in the centre lathe.
- The turret head mounted on the slide or the saddle, as the case may be, is usually hexagonal in turret lathes and circular or hexagonal in capstan lathes, having six holes, one each on each flat face or equi-spaced along the periphery of the circular head.
- The indexing of the tools is in a clockwise direction. After indexing, the automatic feed can be engaged.

4. Bed. The bed is a box shaped gray iron casting with a system of well developed internal stiffening ribs. The turret saddle and cros-slide travel along the ways on the top of the bed.

5. Legs. In each lathe there are two legs, one below each end of the bed. These legs are hollow castings which bear entire load of the bed, of the sliding and stationary parts mounted over the bed and also of the tooling and work holding devices or mechanisms.

Turret Tooling Lay Out

In order to perform any work in a capstan or turret lathe, proper planning for systematic operations should be carried out in advance before setting the work on the lathe. The following procedures should be adopted to plan and execute a work.

1. For effective planning and control, for each capstan or turret lathe, an upto-date capacity chart is an essential requirement. The chart supplied by the manufacturers contains every working details of the machine such as the maximum and minimum diameter of the work that can be mounted, maximum length of stroke of the turret and saddle, maximum length of cross-slide movement, tools available, swing diameter over the carriage, bore diameter on the turret face, bore diameter of the spindle, and the maximum size of the collet chuck that can be mounted on the machine, number of spindle speeds and feeds available, h.p. input, etc.

2. For tooling layout, a drawing of the finished part is also needed.

3. The proper tool selection for different operations should be made from the available tools and tool holders. Standard tools are preferred for a small number of works. Where large number of

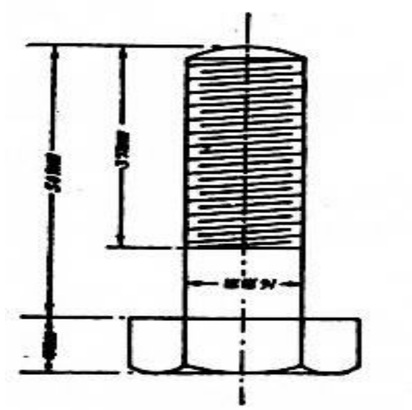
identical pieces are to be manufactured, special tools and tool-holders may be designed for reducing setting and machining time.

4. Once the proper tool selection is made, the finished drawing of the workpiece is superimposed on the capacity chart supplied and the tools to be used are drawn out at the respective positions on the turret face and on the cross-slide tool posts in a regular sequence. The length of travel of tools for each turret face is now calculated from the chart and position of stops decided. Any difficulty in setting and operation is worked out on the paper.

5. The proper spindle speed, feed and depth of the cut are now worked out for each operation.

6. The work and the tools are then set on the machine according to the planned chart.

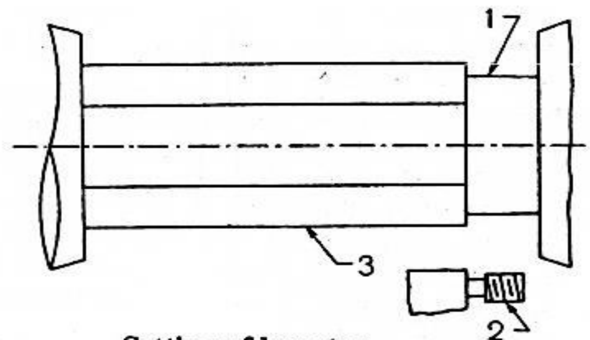
***The planning production of a hexagonal bolt is given below*:**



Hexagonal bolt

1. The capacity chart of the machine is made available.
2. The drawing of the finished hexagonal bolt is taken into consideration. (see Figure)
3. The tools and equipment such as bar stop, roller steady turning tool holder, roller steady bar ending tool holder, self opening die head, chamfering tool, parting tool are collected.
4. The sketch of the work and tools are superimposed on the capacity chart to decide the length of travel of the tool and the position of stops.
5. Proper speeds and feeds for each operation are next calculated.
6. Setting and machining operations are performed in the following order:

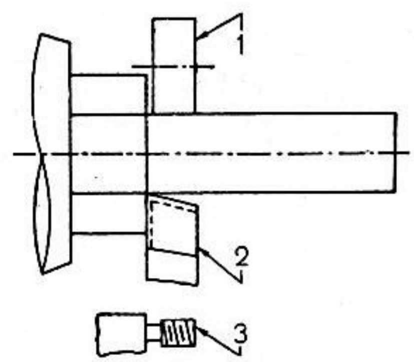
(a) Setting of the bar stops: The bar stop is set at a distance of 70mm from the collet face by using a slip gauge. An extra length of 10mm than the bolt length is allowed, 4mm for parting off and 6mm for clearance off the collet face so that the parting off tool may penetrate deep into the work without any interference (See Figure)



Setting of bar stop

1. Workstop, 2. Position of bar stop, 3. Hexagonal bar.

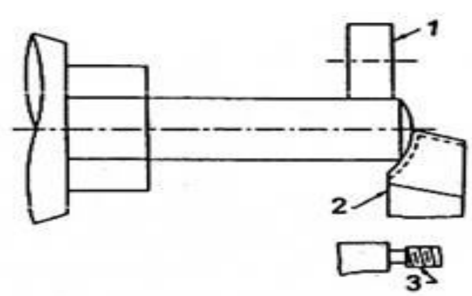
(b) Setting of the roller steady box turning tool: The roller steady box turning tool is set on the next turret face for turning a diameter of 16mm. The stop for turning the tool is set 20mm from the colt face by a slip guage. The rollers are set slightly behind the cutting edges, approximately 1.5mm. (See Figure)



Setting of box turning tool

1. Roller, 2. Turning tool, 3. Position of stop rod.

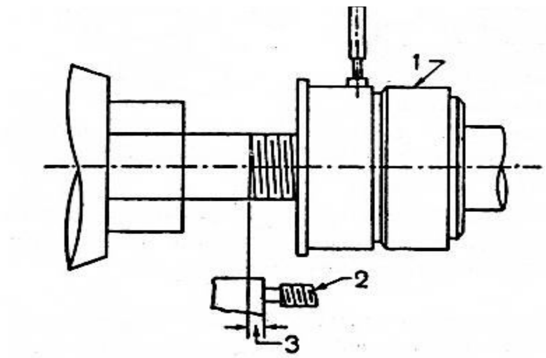
(c) Setting of bar ending tool: The bar ending tool is set on the next turret face and is brought into operation after turning the bar. The stop is adjusted in the position by using a slip gauge (See Figure)



Setting of bar ending tool

1. Roller, 2. Bar ending, 3. Position of stop rod.

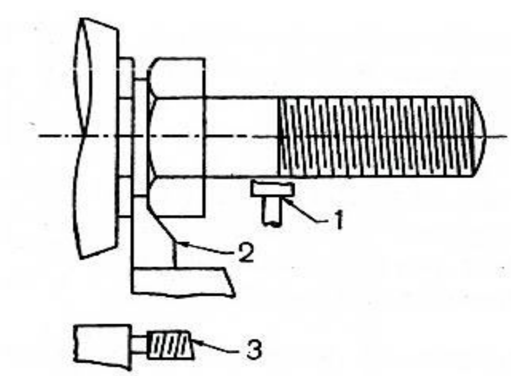
(d) Setting of self opening die head: The self opening die head is mounted on the next face of the turret and the dies are fitted into it to cut a thread of 16mm diameter. The stop is adjusted in a position keeping in view the pulling out length of the die head for self releasing. (See Figure)



Setting of self opening die head

1. Die head 2. Position of stop rod, 3. Pulling out length.

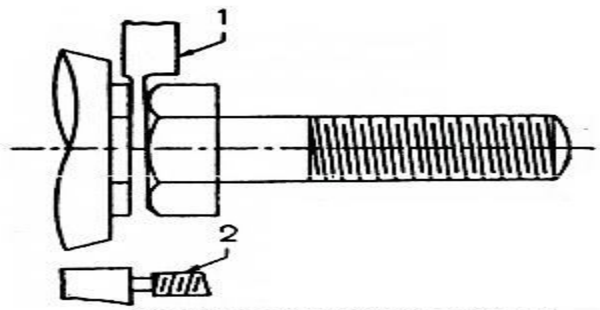
(e) Setting of chamfering tool: the chamfering tool is mounted on the four station turret on the cross-slide and the extreme longitudinal position of the saddle is adjusted by a stop. The cross feed movement of the cross-slide is adjusted by a stop (See Figure)



Setting of chamfering tool.

1. Position of stop on cross-slide, 2. Chamfering tool. 3. Turret saddle stop.

(f) Setting of parting off tool: The parting off tool is set on the rear tool post on the cross-slide and the longitudinal position of the parting off tool is adjusted by the stop set at a distance of 6mm from the turret face (See Figure)



Setting of Parting off tool
1. Parting off tool, 2. Position of stop rod.

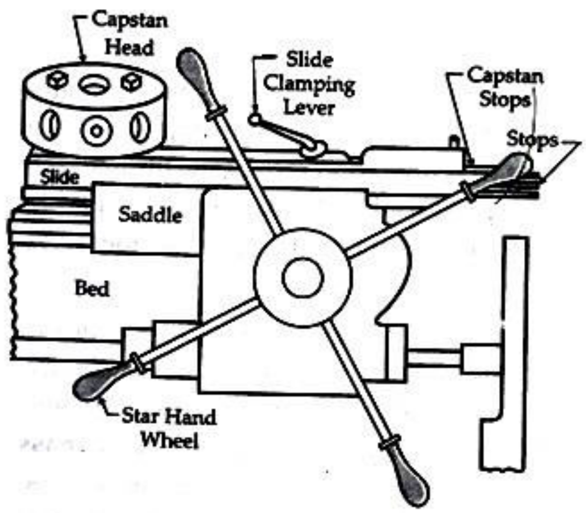
Difference between Turret and Capstan Lathe:

Features of turret lathe that make it a quantity production machine:

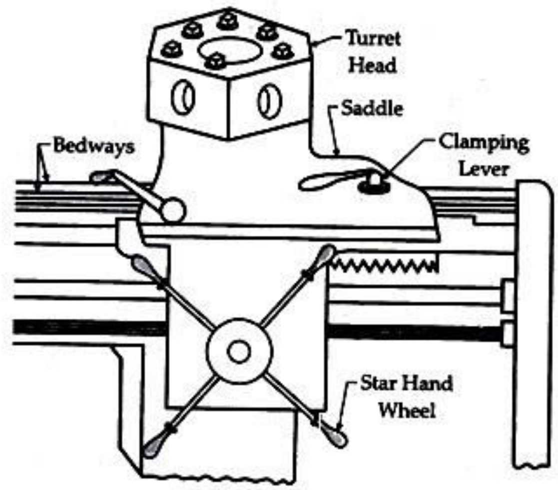
1. Rigidity in holding work and tools is built into the machine to permit multiple and combined cuts.
2. Tools may be set-up in the turret in the proper sequence for the operation.
3. Each station is provided with a feed stop of feed trip so that each cut of a tool is the same as its previous cut.
4. Multiple cuts can be take from the same station at the same time, such as two or more turning and/or boring cuts.
5. Combined cuts can be made; that is, tools on the cross slide can be used at the same time that tools on the turret are cutting.
6. Turret lathes may be fitted with attachments for taper turning, thread chasing, and dupulicating, and can be tape controlled.

A capstan lathe is a lathe designed to use a number of cutting tools mounted in a rotating turret or capstan and arranged to perform turning operations successively.

- This machine is similar both in appearance and operation to a turret lathe, but is used on smaller work.



Mounting the Capstan Head



Mounting the Turret Head

S.No	Aspects	Turret lathe	Capstan lathe
1	Turret position	Turret (head) is mounted directly on the saddle.	Turret is mounted on an auxiliary slide, which moves on the guide ways provided on the saddle.
2	Feeding of tools	For feeding the tools entire saddle is moved.	The saddle is fixed at a convenient distance from the work and the tools are fed by moving the slide.
3	Extent of rigidity	Very high rigidity because all the cutting forces are transferred to the lathe bed.	Because of the overhung of the slide or ram, the tool support unit is subjected to bending and deflection, resulting in vibrations.
4	Capability to handle jobs	Can handle heavier jobs (as a consequence of No.3) involving heavy cutting forces and severe cutting conditions	Since this type of lathe cannot withstand heavy cutting loads, therefore its use is confined to relatively lighter and smaller jobs and precision work.
5	Maximum bar size that can be handled	Upto 200 mm diameter	Upto 60 mm diameter.
6	Tool travel	Almost full length of the bed (since the turret saddle directly rides over the bed way).	Limited tool travel (since the tool feeding is done by the traverse of the slide).
7	Rate of tool feeding	Relatively slower and as such provides more fatigue to the operator's hands.	The tool traverse is faster and offers less fatigue to the operator's hands.

8	Type of carriage	Reach-over type or side hung type.	Usually equipped with the reach-over type only since it is employed for relatively smaller jobs and therefore, does not require a large owing over bed; moreover this type of carriage provides better rigidity.
9	Other provisions	• Heavier designs are usually provided with pneumatic or hydraulic chucks to ensure a firmer grip over heavy jobs • Provision for cross feeding of the hexagonal turret (in some designs) to enable cross feeding of turret head tools.	These lathes do not have such provisions.

Metal Cutting and Machine Tools

UNIT – 4

Objective:

- To familiarize with the working principles of Shaper, Planer and Slotter Machines.
- To impart knowledge on Types of above machines and operations performed on shaper and planer machines.

Syllabus:

Shaping, Slotting & Planning Machines

Shaping, Slotting and Planning Machines**:** Principles of working – principal parts– specifications, operations performed, machining time calculations.

Learning Outcomes:

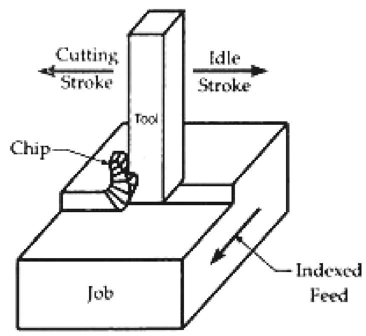
Student will be able to

- State the working principle of Shaper, Planer and Slotter machines.
- List the different types of shaper and Planer machines
- Specify the Shaper machine
- Identify suitable operations performed on shaper, planer and slotter machines to produce variety of components
- Differentiate shaper and planer machines.
- Calculate the cutting speed and machining time to perform variety of operations.

Introduction:

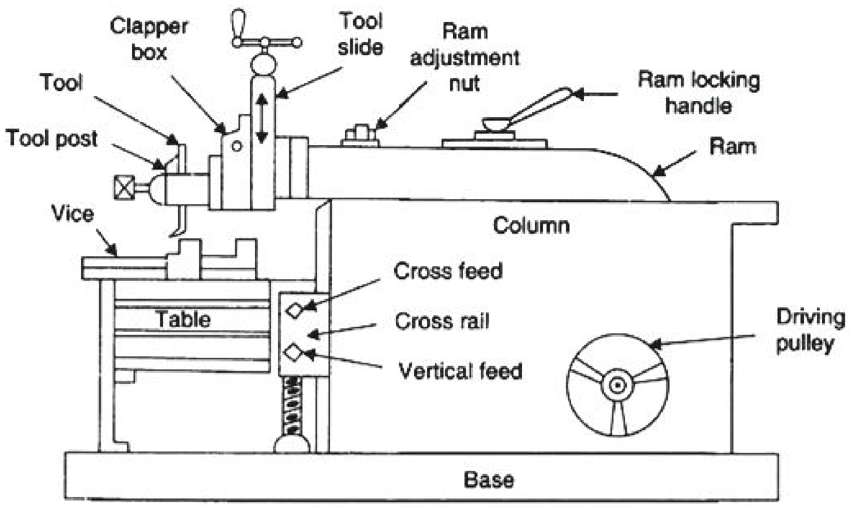
Shaper is a versatile machine which is primarily intended for producing flat surfaces. These surfaces may be horizontal, vertical or inclined. This machine involves the use of a Single point tool held in a properly designed tool holder mounted on a reciprocating ram. The main significance of this machine lies in its greater flexibility on account of ease in work holding, quicj adjustment and use of tools of relatively simple design. On account of this fact it is almost an indispensable machine in tool rooms, die making shops and general repair shops, where only a very few jobs of identical shapes are produced. If properly handled, it can be safely adopted for producing curved and irregular surfaces also.

Working Principle:



The Working principle of a Shaper is illustrated in Figure. In cse of a Shaper, the job is rigidly held in a suitable device like a Vice or clamped directly on the Machine Table. The tool is held in the Tool post mounted on the ram of the machine. This Ram reciprocates to and fro and, in doing so, makes the Tool to cut the material in the forward stroke. No cutting of material takes palce during the return stroke of the ram. Hence, it is termed as Idle stroke. However, in case of a Draw-ctu Shaper, the cutting takes place in the return stroke and the forward stroke in an Idle stroke. The job is given as indexed feed (equal amount after each cut) in a direction normal to the line of action of the Cutting tool.

Principal Parts of a Shaper



Base:

- It is a heavy and robust Cast iron Body which acts as a support for all the other parts of the machine which are mounted over it.

Column:

- It is a Box type Cast iron Body, mounted on the base and acts as a Housing for the Operating mechanism of the machine and the Electricals.
- It also acts as a support for other parts of the machine such as Cross rail and Ram, etc.
- In case of a Hydraulic Shaper, it carries the Hydraulic drive mechanism inside it.
- On its top it carries machines ways, in which the Ram reciprocates, and Vertical guide ways at its front.

Cross-rail:

- It is a heavy cast iron construction, attached to the column at its front on the vertical guide ways.
- It carries two mechanisms; one for elevating the table and the other for cross traverse of the table.

Table:

- It is made of cast iron and has a box type construction.
- It holds and supports the work during the operation and slides along the Cross-rail to provide feed to the work.
- T-slots are provided on its top and sides for securing the work to it.

Ram:

- It is also an iron casting, semi-circular in shape and provided with a ribbed construction inside for rigidity and strength.
- It carries the Tool Head and travels in dovetail guide ways to provide a straight line motion to the Tool. It carries the mechanism for adjustment of Ram position inside it.

Tool Head:

- It is the device in which it held the tool.
- It can slide up and down and can be swung to a desired angle to set the tool at a desired position for the operation.

Vice:

- It is a job holding Device and is mounted on the table.
- It holds and supports the work during the operation. Alternatively, the job can be directly clamped to the machine table.

Specifications of a Shaper:

The shaper is specified as follows:

- Maximum length of the stroke (in mm).
- Size of the table i.e., length, width and depth of the table.
- Maximum horizontal and vertical travel of the table.
- Maximum number of strokes per minute.
- Type of quick return mechanism.
- Power of the drive motor.
- Floor space required.
- Weight.
- Horizontal shapers range in size from small bench models with stroke of 175mm or 200 mm to heavy duty models with strokes as much as 900 mm. shaping machines are commonly provided with power feed ranging from 0.2 to 0.5 mm/stroke.

Classification of Shapers:

According to the type of mechanism used for giving reciprocating motion to the ram:

i) **Crank shaper :**
   - In this type of shaper, a crank and a slotted lever quick return motion mechanism is used to give reciprocating motion to the ram.
   - The crank arm is adjustable and is arranged inside the body of a bull gear (also called crank gear)

ii) **Geared shaper :**
   - In this shaping machine, the ram carries a rack below it, which is driven by a spur gear.
   - This type of shaper is not widely used.

iii) **Hydraulic shaper :**
   - In this type of shaper, a hydraulic system is used to drive the ram.
   - This shaper is more efficient than the crank and geared type shapers.

According to position and travel of ram:

i) **Horizontal shaper :**
   - In this shaping machine, the ram moves or reciprocated in a horizontal direction.
   - This shaper is mainly used for producing flat surfaces.

ii) **Vertical shaper :**

- In this shaper, the ram reciprocates vertically in the downward as well as in upward motion.
- This type of shaping machine is very convenient for machining internal surfaces, keyways, slots or grooves.

iii) Travelling head shaper:

- A travelling head shaper has a reciprocating ram mounted on a saddle which travels sideways along the bed. The ram carries the tool slide.
- Heavy duty jobs which cannot be held on the standard shaper table, are kept stationary on the base travelling head shaper and machined as the ram reciprocates.

<u>*According to the type fo cutting stroke:*</u>

i) Push-cut shaper :

- In this shaper, the ram pushed the tool across the work during cutting operation. In other words, forward stroke is the cutting stroke and the backward stroke is an idle stroke.
- This is the most general type of shaper used in common practice.

ii) Draw-cut shaper :

- In a draw-cut shaper, the ram draws or pulls the tool across the work during cutting operation. In other words, the backward stroke is the cutting stroke and forward stroke is an idle stroke.

<u>*According to the design of the table :*</u>

i) Standard or plain shaper :

- In this type of shaper, the table has only two movements namely horizontal and vertical to give the feed.
- It cannot be swiveled or tilted.

ii) Universal shaper :

- In this shaper, in addition to the above two movements, the table can be swiveled about an horizontal axis parallel to the ram and the upper portion of the table can be tilted abourt a horizontal axis perpendicular to the first axis.
- A universal shaper is mostly used in tool room.

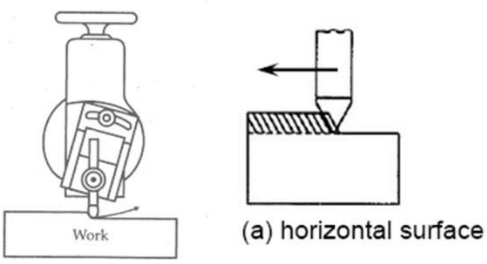
Shaper operations

Several different shapes of jobs can be produced on shapers. However, the basic operations done on a shaper can be broadly classified as follows :

- Horizontal cutting
- Vertical cutting
- Angular cutting, and
- Irregular cutting

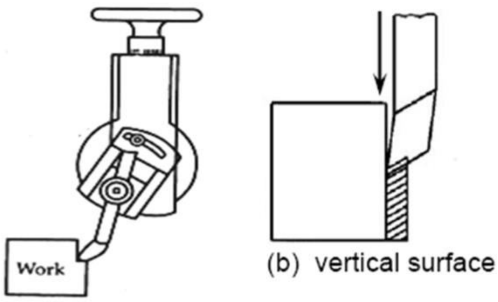
The various shapes of surfaces are the results of eigher one or a combination of more than one of the above four operations.

Horizontal Cutting:



- It is the most common operation performed on a shaping machine.
- In this, the work is fed in a horizontal direction under the reciprocating tool and the surface produced is horizontal and flat.
- For this, the work is either held in a Vice or clamped directly on the machine table, depending upon its size. Before clamping the work, the Vice jaws, Work seat or Table top tested for accuracy. Parallels are used for clamping the work, if it is held in the vice.
- The tool is held in a proper tool holder. It is set at proper inclination and at correct height above the work.
- The depth of cut is adjusted and the machine started.
- Cross feed to the table is given initially by hand, till the cut starts. After that power feed can be employed.
- After the cut is finished, the machine is stopped and the work inspected. If more material is to be removed, the procedure is repeated till the desired surface is obtained.
- A special precaution is required in setting the tool for horizontal cutting. The tool should be held vertically in such a way that its cutting edge points in a direction slightly away from the work. It is set so for the reason that, if sometimes the tool moves, due to the cutting pressure, it will move away from the work instead of digging into it.
- The arrow in Figure indicates this possible direction of movement of the tool under cutting pressure.
- Another precaution to be taken in tool setting is that its cutting edge should not be projected much below the tool holder and vertical slide of the tool head should not be made to overhang tool far below the ram.
- If otherwise, the tool will be weakened and subjected to undue strain. Also, a lot of chatter will result.

Vertical Cutting

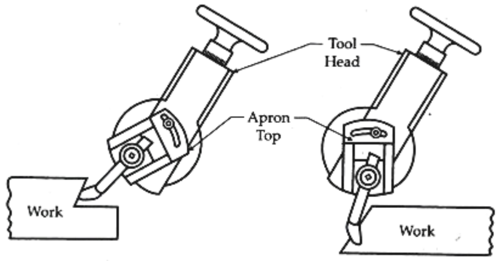


- The tool is fed downward in vertical cutting.
- This sort of tool feed is commonly employed in cutting Grooves, key-ways, tongues, parting off and squaring ends and shoulders.
- When the down feed of the tool is used; except in parting off, the apron top is swiveled in a direction away from the surface to be machined.
- A proper tool setting for vertical cutting is shown in Figure. The down feed to the tool is given by rotating down feed screw of the tool head.

Angular Cutting

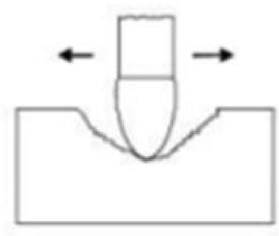
- The operation of Angular Cutting is employed for machining inclined surfaces, beveled surfaces and Dovetails, etc.

- Here again, the down feed of the Tool is used. Proper tool setting is again an important factor here also.
- The Apron top is swiveled in a direction away from the surface to be machined as in Vertical cutting. In addition to that, the tool head is also swiveled, as shown in Figure.



- Alternatively, sometimes an inclined surface is obtained by setting the job in inclined position by setting it on tapered parallels or by other suitable means.

Irregular Cutting



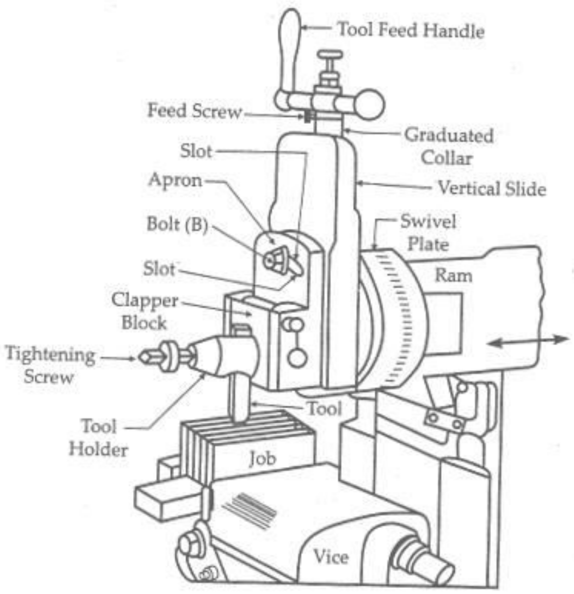
Irregular machining

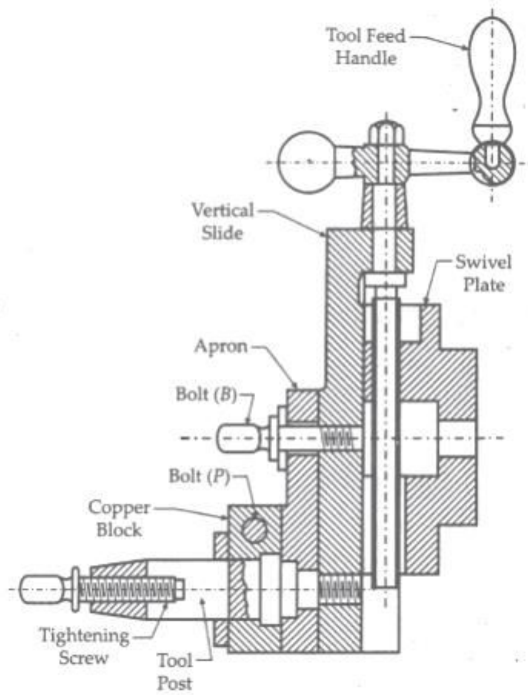
- If an irregular surface is to be machined and it is appreciably narrow, if form tool can easily be used for machining the same.
- Against to this, if a wide irregular surface is to be machined the shape is marked on the side of the job.
- The usual and preferable procedure for such machining is to be first rough machine the surface to about 1.5 mm above the marked the shape.
- Then, bevel the adjust at about 45^0 are more by means of a file and machine off the beveled portion.
- Thus, the job is machined right up to the marked shape. For machining such surfaces, a combination of vertical hand feed to the tool and horizontal power cross feed to the table is to be used.

Tool Head of a Shaper

It is mounted at the front end of the ram as shown in figure. It consists of a vertical slide, which can be moved up and down by rotating feed screw by means of the tool feed handle. The feed screw rotates at its position inside a nut provided at the back of the slide, thus causing slide to move. At the back of the slide is provided a graduated plate, called the swivel plate, which is bolted to the front of the ram. This plate can be unbolted and swivelled to a desired angle on either side to make the tool head inclined with the vertical for machining inclined surfaces. The inclination can be read directly from the graduations provided on the swivel plate.
In front of the slide is provided the apron which carries the clapper box at its bottom. The apron is secured to the slide by means of the bolt B and abuts a back against the slide. Bolt B passes

through a slot made in the shape of a sector in the apron. This facilitates swiveling of the apron also either side of the vertical. For this the Bolt B is unsecured and clamped again after swiveling the apron. The clapper box carries two parallel vertical projections at its front through which pass the pin p.





The clapper block carrying the tool holder, is hinged about this pin such that in the forward stroke of the ram it gets a rigid support at its back by being abutted against the vertical surface of the clapper box and in the return stroke it swings outwards to prevent scratching of the work by the tool. The tool is held vertically in the tool holder and clamped in position by means of the tightening screw.

Vertical feed to the tool is given by rotating the handle provided at the top of the slide. Amount of feed given can be readily noted from the graduated collar provided on the feed screw. It is not necessary to stop the machine while increasing the depth of cut. It can be done while the machine is in operation. Internal details of the tool head are shown in the sectional view.

Quick Return Mechanisms

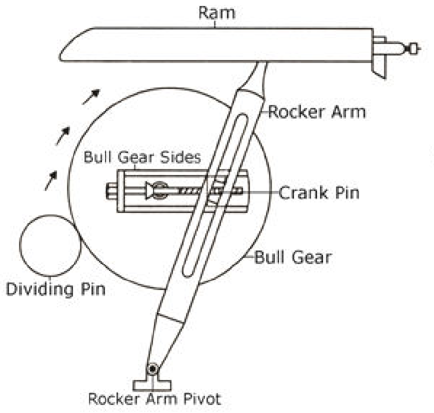
In most of the shapers cutting stroke is forward stroke only and the return stroke is idle. The time spent in this stroke is, obviously, a waste. Similarly, in a draw cut shaper the forward stroke is idle and the time taken by this stroke is also wasted. However fast this idle stroke is made it will definitely take some time and it is not possible, therefore, to reduce it to the zero Value. As such, our endeavor is to use some such mechanism that will reduce this idle time to a minimum. Such a mechanism is known as a Quick Return Mechanism.

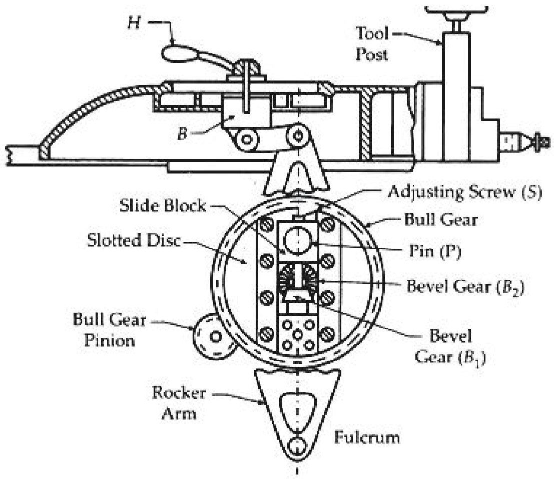
The two common mechanisms used for this purpose are :

- Crank and Slotted link mechanism
- Hydraulic mechanism

Crank and Slotted Link Mechanism:

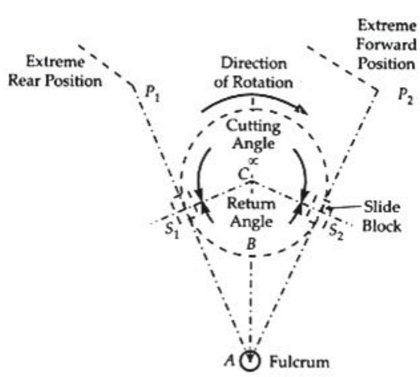
The Crank and slotted link driving mechanism is shown in Figure. It consists of a slotted link, called Rocker Arm, pivoted at its bottom end which forms the Fulcrum, as shown. At its upper end it carries another short link which is attached to the Block B. Block B can be clamped at the desired position by means of the Hand lever H. the Rocket Arm is provided with a slide block, in which revolves the Crank pin P. The slide block can freely slide in the slot provided in the Rocket Arm.





At the back of the Rocker arm a large cast steel gear, called Bull Gear, is provided, which is mounted on a pin attached to the frame of the machine. A slotted disc, carrying a T-slot, is secured to the Bull gear at its front. The Crank pin P is fitted in this slot and ca be moved to any desired position along the same by means of the Bevel Gears B_1. and B_2 and the adjusting screw S. Bevel gear B_2 is concentric with the bull gear and the other bevel gear B_1 is attached to the Adjusting screw at its one end, as shown the axes of B_1 and B_2 being at right angles to each other. The bull gear pinion is mounted on the power shaft and is actuated by the speed control mechanism. This pinion drives the bull gear which, while rotating, on account of the accentricity between its centre and that of the crank pin, makes the Rocker Arm swing about the fulcrum. This, in turn, moves the ram to and fro.

Working Principle:

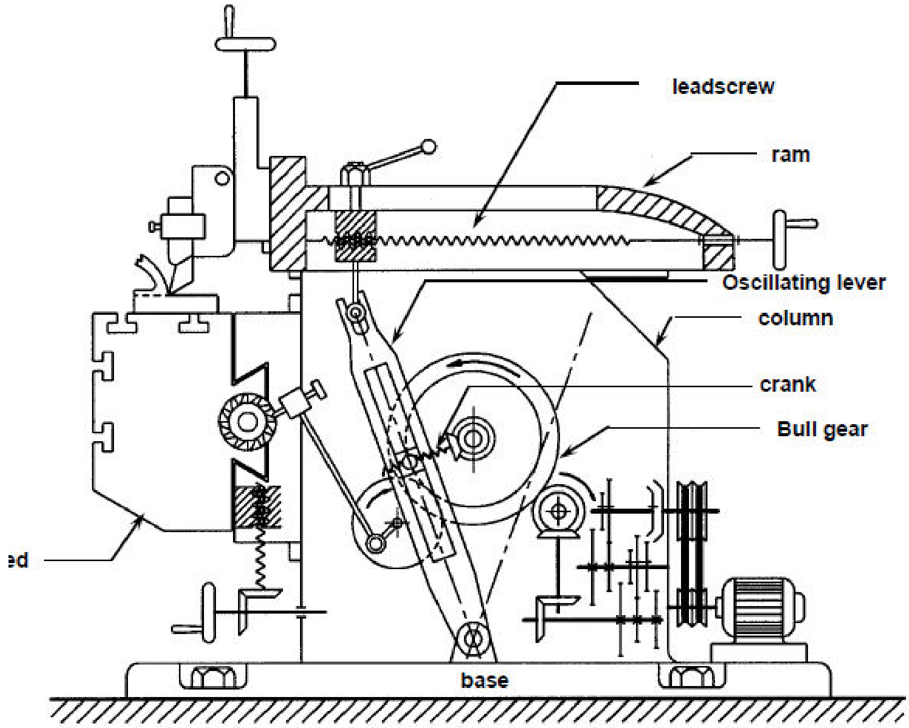


Now let us consider Figure, which represents the same mechanism in a simpler form. The dotted circle represents the path of crank pin centre, During the forward stroke, the Rocker arm moves from position AP_1 to AP_2 and the slide block from S_1 to S_2. In doing so, the slide block has to move through an Angle $\propto$, called the Cutting angle. In the return stroke, the slide block rotates clockwise downwards from S_2 to acquire the position S_1 at the end of this stroke. During this period, it has to move through an Angle β, called the Return Stroke angle or simply Return angle. Since the Bull gear, and so the Crank pin, revolves at a constant speed the time taken during the two strokes will be directly proportional to the corresponding angle $\propto and\ \beta$. Note that angle β is smaller of the two and that is why the time taken during the Return stroke is less than that spent in the forward stroke. The ratio between these two angles, and hence between the corresponding timings, is approximately 3:2. Exact values of these angles are, however, 220° and 140° respectively.

A quick return mechanism is an apparatus to produce a reciprocating motion in which the time taken for travel in one direction is less than in the other. It is driven by a circular motion source (typically a motor of some sort) and uses a system of links and sliding coz u need to not use Wikipedia coz anyone can change it

Quick return is a common feature of tools in which the action is performed in only one direction of the stroke, such as shapers and powered saws, because it allows less time to be spent on returning the tool to its initial position.

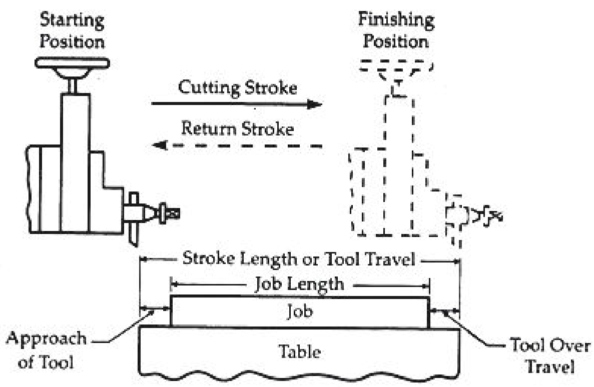
Whitworth quick return mechanism converts rotary motion into reciprocating motion, but unlike the crank and slider, the forward reciprocating motion is slower rate than the return stroke. This is why it is called quick return mechanism. This mechanism is made of a driving crank and of a driven slider crank. In the considered configuration, the fixed pivot of the driven crank is located on the outside of the circle on which the end of the driving crank moves. This leads to an alternated motion of the slider crank. The angular speed of the driven crank is variable. The duration of the motion for its part corresponding to the blue arc is shorter than the one related to the red arc. This is why this device is named quick return mechanism, which was used in crank shapers, with the slow part or the stroke being used for the working time of the tool and the quick part for the non-productive time.



Adjusting the Length of stroke and Ram Position

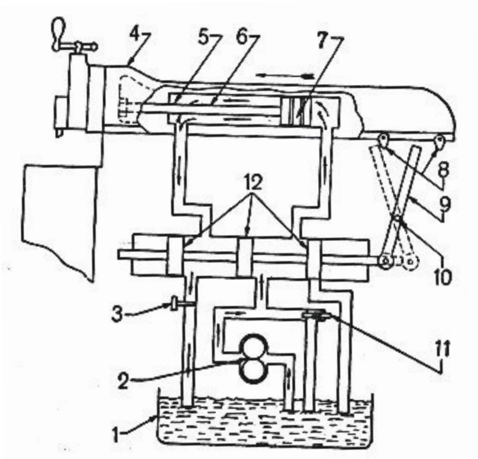
As described above, what we are required to do for varying the stroke length is to provide a corresponding variation in the distance between the Bull gear centre and the centre of crank pin. Since the Bull gear centre is fixed, this variation is provided by moving the slide block and hence the crank pin, away or towards the Bull gear centre, depending upon whether the stroke length is required to be increased or reduced. This is done by rotating the Bevel gear B_2 by turning the Spindle. Gear B_2 will, in turn, rotate the meshing Bevel gear B1 and hence, the adjusting screw. This will move the Slide Block, enabling the required adjustment.

Adjust the Position of Ram:



The next step is to adjust the position of Ram, so as to adjust the Total travel with respect to the job length, so that sufficient allowance is there for the tool to approach the job before the cut starts and an adequate distance is left at the end of the stroke for the tool to be clear of the job. This fixes the starting and finishing positions of the Tool travel and also the two extremities of the Ram stroke as shown in Fig.9.7. Before adjusting the Ram position, the length of stroke should be determined and set accordingly. Keeping the Handle H, tight the ram should, then, be moved back to the possible extreme rear position. Then release the Handle H and slide the Ram to the required position. Clamp the handle H again and check the travel by moving the Ram with the help of Wheel.

Hydraulic Mechanism:



1. Oil reservoir, 2. Oil pump, 3. Throttle Valve, 4. Ram, 5. Cylinder, 6. Piston rod, 7. Piston, 8. Reversing dog, 9. Reversing lever, 10. Reversing lever pivot, 11. Relief valve, 12. Valves.

In a hydraulic shaper the ram is moved forward and backward by a piston moving in a cylinder placed under the ram. The machine mainly consists of a constant discharge oil pump 2, a valve chamber, a cylinder, and a piston 7. The piston rod 6 is bolted to the ram body. As shown in Figure, the oil under high pressure is pumped from the reservoir *l* and is made to pass through the valve chamber to the right side of the oil cylinder 5 exerting pressure on the piston 7. This causes the ram 4 connected to the piston 7 to perform forward stroke, and any oil present on the left side of the cylinder is discharged to the reservoir through the throttle valve 3. At the end of extreme forward stroke, the shaper dog 8 hits against the reversing lever 9 causing the valves 12 to alter their positions within the valve chamber. Oil under high pressure is now pumped to the left side of the piston causing the ram to perform return stroke. Oil present on the right side of the piston is now discharged to the reservoir. At the end of the return stroke another shaper dog hits against the reversing lever altering the direction of stroke of the piston and the cycle is thus repeated.

The quick return motion is effected due to the difference in stroke volume of the cylinder at both ends, the left hand end being smaller due to the presence of the piston rod. As the pump is constant discharge one, within a fixed period, the same amount of oil will be pumped into the right or to the left hand side of the cylinder. This will mean that the same amount of oil will be packed within a smaller stroke volume causing the oil pressure to rise automatically and increasing the speed during the return stroke. *The length and position of stroke is adjusted* by shifting the position of reversing dogs. *The cutting speed* may be changed by controlling the throttle valve 3 which regulates the flow of oil.

Advantages of hydraulic drive :

- The cutting stroke has a more constant velocity and less vibration and less vibration is induced in the hydraulic shaper.
- The cutting speed is generally shown on an indicator and does not require calculation.
- Both the cutting stroke length and its position relative to the work may be changed quickly without stopping the machine.
- Ram movement can be reversed instantly anywhere in either direction of travel.
- The hydraulic feed operates while the tool is clear of work.
- More strokes per minute can be achieved by consuming less time for reversal and return strokes.
- Since the power available remains constant throughout, it is possible to utilize the full capacity of the cutting tool during the cutting stroke.

Disadvantages :

- The stopping point of the cutting stroke in a hydraulic shaper can vary depending upon the resistance offered to cutting by the work material.
- It is more expensive compared to the mechanical shaper.

Cutting Speeds and Feeds

With regard to the selection of proper cutting speed and feed it is advisable to use the standard tables provided by the manufacturer's along with the machine.

However, if needed, the cutting speed can be calculated, thus:

Let L Meters be the length of stroke

And S=No. of strokes per minute.

Now, the distance travelled by the tool per minute=L×S meters.

Or, in other words, we can say that the length of metal cut per minute by the tool = L×S meters.

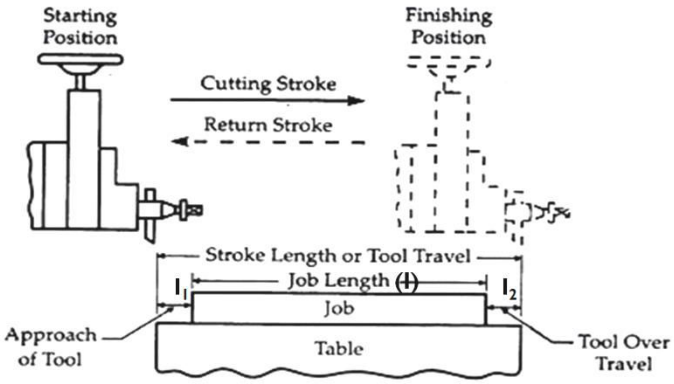
It is important to note here that the return stroke is idle and the time spent during the same is wasted. This time is 2/5 of the total time taken. So the Actual time taken in cutting the metal is 3/5 of the total. That is, the time actually spent in cutting L×S meters is 3/5 minutes and not one minute.

i.e., in 3/5 minute the tool cuts a length = L×S meters

Therefore, in 1 minute the tool will cut $= \frac{L \times S \times 5}{3} meters$

or, Cutting speed = 1.67 LS meters per minute (approx.)

Estimating Machine Time



Refer to Figure, for understanding the tool positions and other related terms.

Let L = Length of stroke or Tool travel, in meters.

l = Length or breadth of job, over which the tool passes, in meters.

l_1 = Tool approach i.e., the distance it has to travel before starting actual cutting in meters.

l_2 = Over travel, i.e., the distance through which the tool travels beyond the work surface in meter.

f = Feed per cycle, in mm.

m = Ratio of return time to cutting time.

v_1 = Average cutting speed, in meters per min.

v_2 = Average return speed, in meters per min.

n = No. of cycles required.

Now,

Cutting speed (v_1) = $\frac{Length\ of\ cutting\ stroke}{Time\ taken\ in\ cutting\ stroke}$

∴ Cutting time = $\frac{Length\ of\ cutting\ strok}{Cutting\ speed\ in\ m/min} = \frac{L}{V_1}$

$= \frac{l+l_1+l_2}{V_1} min$

And Non-cutting time or Idle time = $\frac{Length\ of\ stroke\ in\ meters}{Return\ speed\ in\ meters\ /min.} = \frac{L}{V_2} = \frac{l+l_1+l_2}{V_2} min$

Now, Total time per cycle = Cutting time + Idle time

$$= \frac{L}{V_1} + \frac{L}{V_2} = \frac{L}{V_1} + K \times \frac{L}{V_1}$$

[where K=Ratio of Idle stroke time to cutting stroke time]

∴ Total Time = $\frac{L}{V_1} + K\frac{L}{V_1} = \frac{L(1+K)}{V_1} minutes$ …(i)

For shaping a workpiece an allowance of about 5mm is left on either side of it. Thus, the Shaping width of the workpiece is obtained as :

Shaping width B = Width of workpiece + 2 × allowance

No.of Cycles required (n) $= \frac{Shaping\ width}{Feed\ per\ cycle} = \frac{B}{f}$

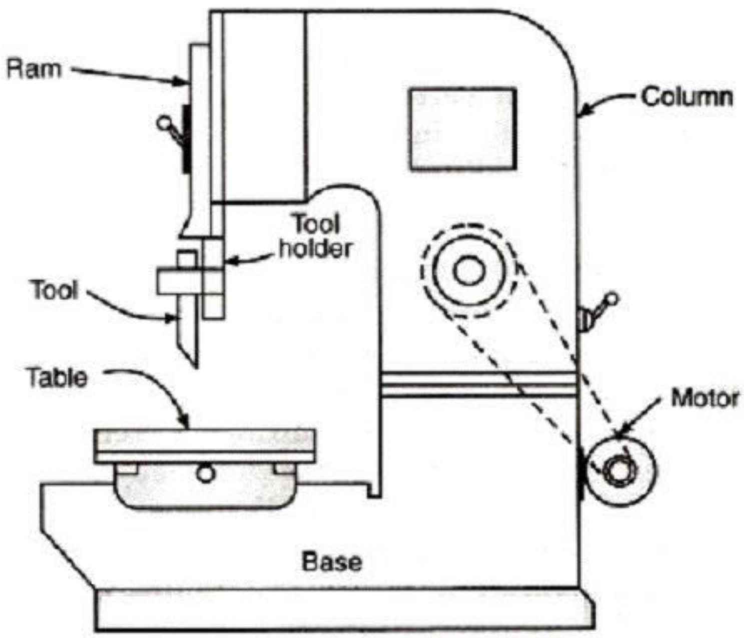
Machining time = No.of cycles × time required for each cycle

$$= \frac{B}{f} \times \frac{L(1+k)}{V_1} \text{min} = \frac{LB(1+K)}{f \times V_1} min$$

Slotting Machine

A Slotting Machine or Slotter has its own importance for a few particular classes of work. Its main use is in cutting different types of slots and it certainly proves to be most economical so far as this kind of work is concerned. Its other uses are in machining irregular shapes, circular surfaces and other premarket profiles, both internal as well as external. Its construction is similar to that of a vertical shaper. Its ram moves vertically and the tool cuts during the down stroke only.

Main parts of a Slotter:-



The main parts of a Slotting Machine are shown by means of a block diagram.

The parts illustrated are as follows:

Base:

It is a heavy cast iron construction and is also known as Bed. It acts as support for the column, the driving mechanism ram, table and all other fittings. At its top it carries horizontal ways, along which the table can be traversed.

Column:-

It is another heavy CI body which acts as a housing for the complete driving mechanism. At its front it carries vertical ways, along which the ram moves up and down.

Table:-

Usually a circular table is provided on slotting machines. In some heavy duty slotters, such as a puncher slotter, either a rectangular or circular table can be mounted. On the top of the table are provided T-slots to clamp the work or facilitate the use of fixtures, etc.

Ram:- It moves in a vertical direction between the vertical guide ways provided in front of the column. At its bottom, it carries the tool post in which the tool is held. The cutting action takes place during the downward movement of the ram.

Saddle:- It is mounted on the base and can be moved longitudinally on the guide ways.

Types of Slotting Machines:

Punch Slotter: A heavy duty rigid machine designed for removing large amount of metal from large forgings or castings

Tool room Slotter: A heavy machine which is designed to operate at high speeds. This machine takes light cuts and gives accurate finishing.

Production Slotter: A heavy duty slotter consisting of heavy cast base and heavy frame, and is generally made in two parts.

Slotter Machine Specifications:-

- Slotting machines are specified by maximum length of the stroke.
- Maximum size of the job that can be machined easily.
- Maximum motion of the table sliding with the work piece.
- Amount of material that can be machined in a single stroke.
- Maximum length and width of the base that can withstand heavy jobs.
- The length of the ram stroke may be 320mm.
- The power of the motor may be 7KW.
- The whole dimensions of slotter may be 2650×1810×2890mm.
- The maximum diameter of the work table of machine may be 360mm
- The longitudinal travel of the table may be 650mm and cross 500mm.
- Table feed per double stroke of the tool may be circular 0.1-1.4mm, cross 0.2-2.4mm and longitudinal 0.2-2.4mm.

Operations performed on slotter:-

Machining Flat Surfaces:-

For machining a flat surface the work is mounted on a parallel strip such that the tool will not touch the work table at the end of the cut. Metal is removed as the tool travels past the work. The cross feed is given at the beginning of each cutting stroke.

For machining cylindrical surfaces the tool is set readily on the work. The feed is given by rotary table at the beginning of the cut.

Machining the Circular Surfaces:-

During this process, the work is placed centrally on the table and is clamped at this position by means of clamps and packing pieces. Before starting the machine the tool is set readily and the saddle is clamped in position. During machining, the feed is given by rotating the table through the required arc and thus producing the required circular surface.

Machining a Rectangular Slot, Key Ways and Grooves:-

Internal and external grooves and keyways are cut conveniently using slotter. For cutting equally spaced grooves on a periphery of work, feed is given by the rotary table. The graduations on the rotary table facilitates the indexing the work.

Machining Irregular Surfaces and Cam Profiles:-

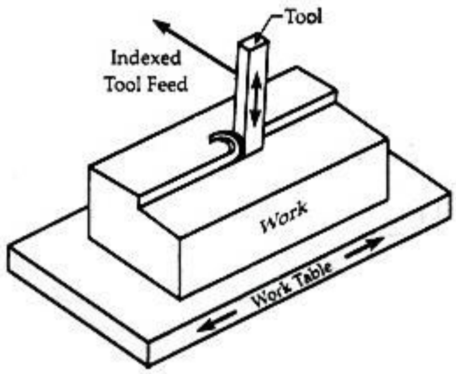
For machining irregular contours and cam profiles the work is fed simultaneously in three directions i.e. by combining cross, longitudinal and rotary feed movements of table.

Planer Machine

Introduction:

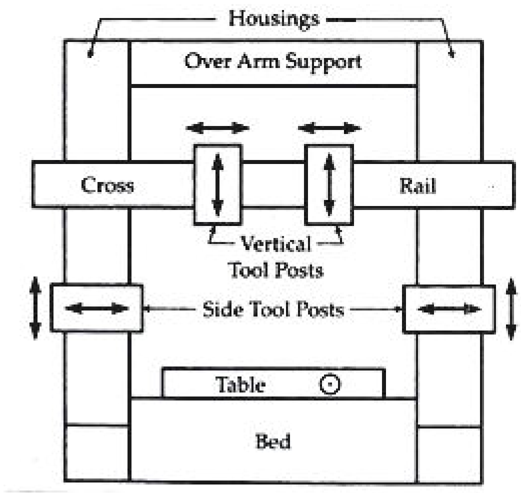
- Planing is one of the basic operations performed in machining work and is primarily intended for machining large flat surfaces.
- These surfaces may be Horizontal, Vertical or Inclined.
- In this way, the function of a planing machine is quite similar to that of a shaper except that the *planer is basically designed to undertake machining of such large and heavy jobs* which are almost impracticable to be machined on a shaper or milling machine.
- It is an established fact that the Planing Machine proves to be most economical so far as the machining of large flat surfaces is concerned.
- However, a Planing Machine differs from a Shaper in that for machining, the work, loaded on the table, reciprocates past the stationery tool in Planer, whereas in a Shaper these tolls reciprocates past the stationery work.

Working Principle of a Planer



- The Principle involved in machining a Job on a Planer is illustrated in Figure.
- Here, it is almost a reverse case to that of a Shaper.
- The work is rigidly held on the Work table or Platen of the machine.
- The tool is held vertically in the Tool-head mounted on the Cross-rail.
- The work table, together with the job, is made to reciprocate past the vertically held tool. The indexed feed, after each cut, is given to the tool during the idle stroke of the Table.

Main Parts of a Planer



A Planer consists of the following main parts, as illustrated by means of a block diagram in Figure:

- Bed
- Table or Platen
- Housings or Columns
- Cross-rail
- Tool heads
- Controls

1. Bed

- It is very large and heavy Cast iron Structure, which is provided with cross ribs for additional strength and stiffness, as the same supports the whole structure of the Machine over it.
- In case of Large Planers the Bed is sometimes made in two parts, which are properly machined and then bolted together to form a single length of Bed.
- Devices like Leveling jacks or Pads, etc., are provided at its bottom for the purpose of leveling during installation. It is about two times longer than the Table it carries over it.
- At its top, it carries either V-ways, or Flat ways (only in case of large planers), to support and guide the table.
- All small and medium size Planer Beds carries two V-ways, one on each side.
- Beds of large planers may, however, carry more number of ways, of which some may be flat, as indicated above. All the ways are straight, parallel, accurately machined and scraped. These ways should be constantly lubricated and in view of the same all Modern Planers are provided with Pressure lubrication at several points along the ways.

Table

- The Table or Platen (as it is frequently called) is also made of cast iron with an accurately machined top.
- It may be a single piece casting or made in two pieces, bolted together in the same ways as the two piece bed.
- It carries a Box type construction, provided with strengthening ribs under it in order to make it strong enough to support the heavy work over it. At its Top it carries longitudinal T-slots and holes to accommodate the claiming bolts and other divides.
- The work is directly mounted and clamped on the table by means of various devices using the

T-slots and holes.

- Under the table, Chip pockets are cast integral with it for collecting and removing the chips.
- On its side, the table carries adjustable stops to reverse its motion at the end of each stroke.
- At its both ends, it carries a Trough to collect the chips. Occasionally, however, these troughs may be used to support overhanging parts of large components.

Housings or Columns

- They are also sometimes called columns or Uprights. These vertical members are situated on both sides in case of a Double Housing Planer and on one side only in case of an open side planer.
- Inside them, they carry the different mechanisms for transmission of power to the upper parts of the machine, from the main drive viz., Cross-rail elevating screws, Vertical feed shaft and Cross feed bar, etc,.
- At their front, they are very accurately machined to form Vertical ways along which the cross rail slides up and down.
- Where side tool-heads are used, they also slide vertically along the same guide ways.

Cross-rail

- It is a horizontal member of heavy structure which connects the two Vertical housings of the machine.
- It provides additional rigidity to the machine.
- By means of the Elevating screws it can be moved up and down along the ways provided on the housings.
- Clamps are provided to lock the cross-rail in any desired position along the columns. These clamps may be operated by hand or power.
- Also a suitable leveling device is incorporated to ensure that the cross-rail is perfectly horizontal before clamping.
- Accurately finished ways are provided at the front of the Cross-rail for the two vertical tool heads.
- Inside the rail are provided the feed rods for vertical power feed and cross feed to the tools.
- The rail is made sufficiently long, to project on both sides of the housings, so that one of the two tool heads can be pushed out to one end.
- This will enable the other tool head to travel freely cross-wise from one end of the table to the other, covering the entire width of the job.

Tool heads

- The planer tool heads, both in construction as well as operation, resemble very much with the shaper tool heads.
- At the most four tool heads can be fitted in a planer and any or all of them can be used at a time.
- Two tool heads can be fitted in vertical position on the cross-rail and the other two on the vertical columns. Each column carries one side tool head.
- The method of mounting is similar for all the tool heads.
- All the four tool heads work independently, such that they can operate separately or simultaneously, as desired.
- The tool heads on the cross-rail can travel horizontally, along the rail. They can also be raised

or lowered by moving the cross-rail up or down. Also, the tools can be fed downwards by rotating the down feed screw.

- Similarly, the side tool heads can move up and down along the vertical column ways. Also their tools can be fed horizontally into the job or a t desired inclination.
- A swivel plate is incorporated between the slide and the saddle. This enables the tool head to swivel through an angle of 70° on either side from its normal position. Exactly in the same way as in a shaper head, the Apron of the Planer head can also be set at an inclination whenever needed.
- Both hand and power feeds can be employed, for all the tool heads, but power feeds are commonly used.
- The clapper block is also hinged, as in shaper head, in order to avoid scratching of machined surface by the tool during the idle stroke.

Controls

- Various controls for starting, operating and stopping the various mechanisms, automatic cutting off speed and feed regulation and similar other functions are usually provided within a quick approach of the operator of the machine.
- A good number of these are usually provided on a suspended pendant so that the operator can take them to any convenient position according to his needs.
-

MACHINE SIZE AND SPECIFICATIONS

Planers are made in different sizes and they are specified by the following main dimensions:

- Horizontal distance between the two vertical Housings.
- Vertical distance between the Table top and the Cross-rail,
- Maximum length of table travel or length of stroke.

The above three are the Principal dimensions, but while ordering for a Planer a number of other particulars are also required to be given, in addition to these, in order to specify the Planer fully. These particulars are the following.

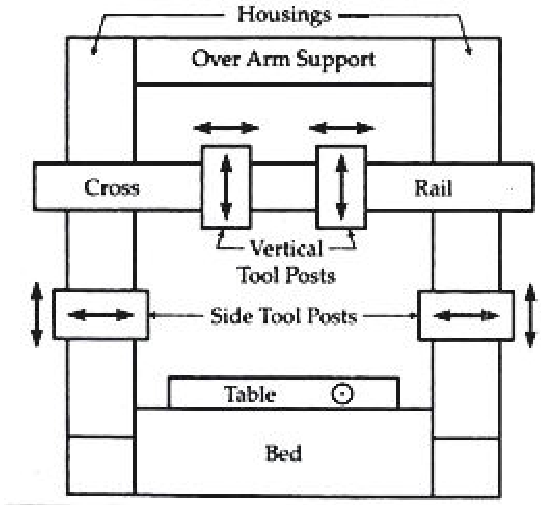
- Length of Bed.
- Length of Table.
- Method of driving-Common or Individual
- Method of driving the Table-Geared or Hydraulic, etc.
- H.P. (or kW) of Motor.
- Number of additional Tool Heads required.

Types of Planers

A fairly large variety of planers of different designs of sizes is available in the market. They are, however, classified broadly into the following types :

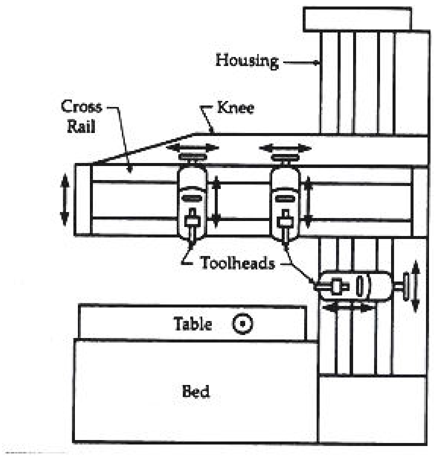
- Standard or Double housing planer,
- Planer Miller,
- Pit Planer,
- Plano-Guillotine Shearing Machine.
- Open side Planer,
- Plate Planer,
- Divided table Planer, and

A Standard or Double Housing Planer



- This is the most commonly used type of Planer.
- It consists of two vertical Housings or Columns, one on each side of the bed.
- The housings carry vertical machined and scraped ways.
- The cross-rail is fitted between the two housings and carries one or two vertical tool heads.
- The work table is mounted over the bed.
- Side tool heads are fitted on the vertical housings.
- Details of the main parts of this machine are shown in Figure.
- These machines are Heavy duty type and carry a very rigid construction.
- They employ high speeds for cutting, but the size of the work they can handle is limited to the width of their table, i.e., the horizontal distance between the two columns. Extremely large and heavy castings, like machine beds, tables, plates, sided, columns, etc., which normally carry sliding surfaces like guide ways or dovetails on their longitudinal faces, are usually machined on these machines.
- Also, because of a long table and larger table travel, on either side of the columns, it is possible to hold a number of work pieces in a series over the bed length and machine them together. This will affect a substantial saving in machining time.
- Further, because up to four tool heads, one each on the side columns and two on the cross-rail, can be employed separately or simultaneously, a number of surfaces can be machined simultaneously. This affects further reduction in machining time.
- Also, because of high rigidity of the machine and robust design of cutting tools, heavier cuts can be easily employed, which heads to quicker metal removal and a reduced machining time.
- Thus, an overall picture emerges that the employment of this type of machine, apart from its capacity to handle such heavy and large jobs which are difficult to be handled on other machines, leads to faster machining and reduced machining time and, hence, to economical machining. However, considerable time is used in setting up a planer.

An Open side Planer

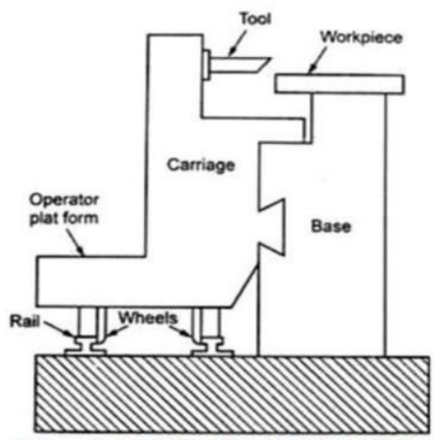


- This type of planer consists of only one housing, situated vertically on one side of the bed, and the other side is left open without any obstruction.
- The cross rail is of cantilever type and is wholly supported on the single column. Because of the absence of one housing, only three tool heads can be used as a maximum. Rest of the features is the same as in Double Housing Planer. The main parts of an Open side planer are shown in Figure.
- The advantage of an open side planer lies in its adaptability for machining those components which are much wider than could pass between the housings of a standard planer of the same size.
- Special care is always needed in designing this machine as it is likely to be subjected to severe twisting forces during the operation on account of the absence of one housing and the cantilever type cross rail.
- In case of exceptionally large and over-hanging parts, the outer end is supported on an auxiliary rolling table. A rest is mounted on this table, which slides on the rollers in it, and the work is fastened to this rest.

Planer Miller or Plano Mill

- It is actually a combination of the two machines and hence the name planer Miller.
- In construction, it resembles a standard double housing planer but the conventional tool heads of a planer are replaced by Milling Heads carrying revolving cutters.

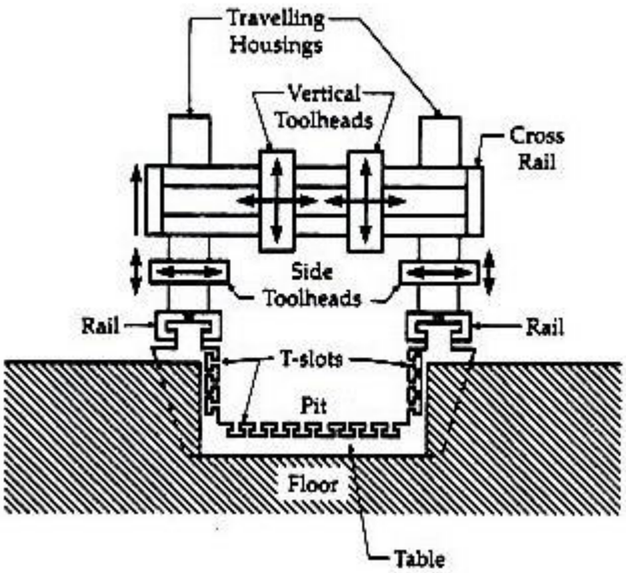
Plate Planer or Edge Planer



- This machine differs completely from the conventional type of planer, both in construction as well as operation.

- Contrary to the conventional planer, the Bed and the Table of the Plate Planer are a fixed unit and the work is mounted on the latter.
- The toolhead is mounted on a movable carriage which can travel longitudinally along the bed.
- The operator also stands on a platform, attached to the carriage, and travels along with it during machining. Thus, in operation, the work remains stationary while the tool moves to and fro.
- The slide rest of the carriage is so constructed that the tool can be given vertical or transverse movement, as desired.
- The tool holder can hold one or more tools at a time and can also be tilted for machining slant surfaces; such as for cutting bevels.
- The movement of the carriage is accomplished by means of a rack and pinion mechanism. The pinion is mounted on a spindle attached to the carriage and it meshed with a rack running the full length of the Bed.
- It is a single purpose machine constructed for such special work as machining the edges of boiler plates, ships' for pipelines and for welding. The work is clamped to the table by pneumatic or Hydraulic means.

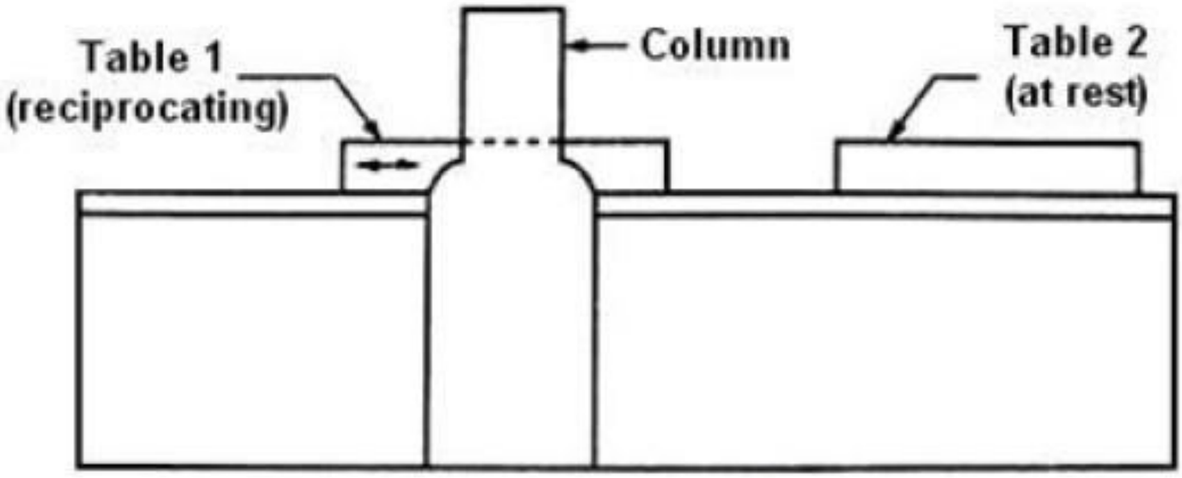
Pit Planer



- It is shown by means of a block diagram in Figure.
- This machine is specially designed for machining such long, heavy and tall work that cannot be machined on the conventional type of planers.
- The job is either mounted on a stationary table (plate) or on the floor inside a Pit. Sometimes, however, no clamping is needed when the work is extremely heavy.
- The machine is provided with two short vertical housing which carry a cross-rail.

- One or two tool heads are mounted on the cross-rail and two side tool posts on the housings, if required.
- This whole unit travels along the horizontal ways to and fro and, thus, the tool moves past the work for machining the surface of the latter.
- Usually upper horizontal and inclined surfaces of the work piece are machined on these planers.

Divided Table Planer



- It is also known as Tandem Planer. In this machine, the table is constructed in two or more parts which can be joined together to hold a very long work or used separately as desired.
- It is quite well known that a fairly large part of the total time, spent on machining a job, is spent in its proper setting particularly because of the difficulty in handling the work due to its excessive heavy weight.
- For such items, particularly when identical parts are to be machined on large scale, this machine with divided table is employed such that when the work on one table is being machined the same is being s8imultaneously set up on the other table, in readiness for replacing the former after the operation is over. It, thus affects a considerable savings in setting time.

Plano-Guillotine Shearing Machine

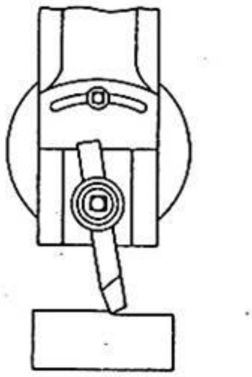
- It is also a special purpose machine, used for cutting and preparing ends of large plates.
- It is provided with a traversing cutter head which carries a rotary Disc cutter instead of a single point tool.
- The standard cutter will always cut square with the surface.
- However, other cutters can be fitted to cut to an angle.
- Sometimes, a swiveling type of Head is also provided in order to produce angular cuts. The plate is sheared off in a single traverse of the cutter head; the machine, thus, giving a much higher output than a conventional planer.

Planer Operations

Operations performed in a planer are similar to that of a shaper. The only difference is that a planer is specially designed for planning large work, whereas a shaper can machine only small work. The common types of work machined in a planer are: the bases and tables of all kinds of machine tools, large structures, frames of different engines and identical pieces of work which may be small in size but large in number. The common operations performed on planer are:

1. Planing flat horizontal surfaces.
2. Planing vertical surfaces.
3. Planing at an angle and machining dovetails.
4. Planing curved surfaces.

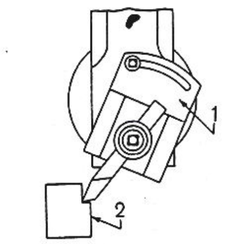
Planning horizontal surfaces:



Machining horizontal surface

- While machining horizontal surface, the work is given a reciprocating movement along with the table and the tool is fed crosswise to complete the cut.
- Both the railheads may be used for simultaneous removal of the metal from two cutting edges.
- The work is supported properly on the table; proper planning tool is selected; the depth of cut, speed and feed are adjusted and the work is finished to the required dimension by taking roughing and finishing cuts.
- The tool setting is similar to that shown in Figure.

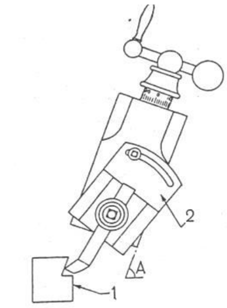
***Planing Vertical Surface*:**



Machining vertical surface
1. Apron 2. Work.

- The vertical surface of a work is planed by adjusting the saddle horizontally along the crossrail until the tool is in a position to give the required depth of cut.
- The vertical slide is adjusted perpendicular to the planer table and the apron is swiveled in a direction so that the tool will swing clear out of the machined surface during the return stroke.
- The down feed is given by rotating the down feed screw.
- The tool setting is similar to that shown in Figure.

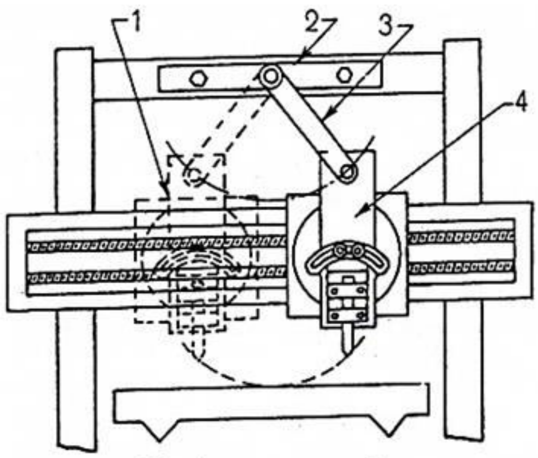
Planing angular surface:



Machining angular surface
1. Work, 2. Apron, A, Swivelling angle of the vertical slide.

- For dovetail work, cutting V-grooves, etc. the tool head is swiveled to the required angle and the apron is then further swiveled away from the work to give relief to the tool cutting edge during the return stroke.
- By rotating the down feed screw the tool is fed at an angle to the planer table. The tool setting is similar to that shown in Figure.

Planning Formed Surface:



Planing concave surface
1. Toolhead, 2. Bracket, 3. Radius arm 4. Vertical slide.

- Figure illustrates a simple method of planning a concave surface with the aid of a special fixture consisting of a radius arm 3 and a bracket 2.
- The bracket is connected to the cross member attached to the two housings.

- One end of the radius arm 3 is pivoted on the bracket and the other end to the vertical slide 4 of the tool head.
- The down feed screw of the tool head is removed. While planning, the cross rail and the tool which causes the saddle to traverse the cross rail and the tool which is guided by the radius arm 3 planes a concave surface.
- The radius of concave surface is dependent upon the length of the radius arm.

Cutting Speed, Feed and Depth of Cut

In general, frequent variations in cutting speeds are not needed for the reason that the only variations to be taken into account are the kind of cutting tool and the materials to be machined. Length of work, sizes of cutting tools and similar other factors have no influence on the same. Moreover, usually the planer is used for machining heavy jobs and, obviously, heavier cuts are to be employed. With the result, the planer uses much slower speeds than most of the other machines in the shop. If, however, a selection is to be made for cutting speed a nearest suitable speed, depending upon the materials of the tool and the work, should be selected.

Commonly used planers usually employ a cutting speed of 6 to 15 meters per minute and a return speed of about 30 meters per minute. A cutting speed up to about 25 meters per minute and a return speed of up to 45 meters per minute is obtained on Hydraulic Planers. The amount of feed and depth of cut largely depend upon the material of the work, required surface finish and the rigidity of the machine.

Difference between Planer and Shaper

Planer	Shaper
1. It is a heavier, more rigid and costlier machine	It is a comparatively lighter and cheaper machine.
2. It requires more floor area.	It requires less floor area.
3. It is used for machining large flat surfaces-horizontal, vertical and inclined.	It is also used for the same purposes but for relatively smaller surfaces.
4. The work is usually clamped directly on the machine table by means of suitable fixtures or clamping devices.	The work may be clamped directly on the table or held in a vice or chuck.
5. Cutting takes place by reciprocating the work under the tool.	Cutting takes place by moving the cutting tool over the job.
6. Indexed feed is given to the tool during the idle stroke of the work table.	Indexed feed is given to the work during the idle stroke of the ram.
7. Heavier cuts and coarse feeds can be employed	Very heavy cuts and coarse feeds cannot be employed.
8. Several tools can be mounted and employed simultaneously, usually four as a maximum, facilitating a faster rate of production.	Usually only one tool is used on a shaper.
9. Because of its large stroke length and table size a number of jobs, requiring machining of	This is not possible on shaper until and unless the job and surface sizes are too small, which can be

identical shapes, can be held in series and machined simultaneously in a single setting.	conveniently held on the table, say in a vice.
10. The tools used on a planer are larger, heavier and stronger than those used on a shaper.	The tools used on a shaper are smaller and lighter.

Driving Mechanisms

Four different methods are employed for driving the table of a planer. They are as follows:

1. **Crank Drive:** Similar to the one employed for driving the Ram of a Shaper. It is, however, obsolete now.
2. **Belt Drive**: In this, the motor drives a countershaft which, in turn, drives the main driving shaft through belts and a set of fast and loose pulleys. This shaft drives a pinion which meshed with a Rack under the machine table.
3. **Direct Reversible Drive:** In this, a reversible motor, through a set of reduction gears, drives the pinion which meshes with the rack provided under the machine table.
4. **Hydraulic Drive** It is quite similar to the one used for driving the Ram of a shaper. Of course, more than one cylinder can be used for achieving different speeds.

Whatever may be the methods of drive used for a planer table, it should essentially meet the following operating requirement.

- It should be long lasting and its control should be easy.
- It should be capable of providing several quick and safe reversals of the table continuously without any chances of breakdowns.
- It should incorporate a mechanism for faster return of the table, accurately at the same point in each stroke, without any shock or vibrations. The return speed of the table is supposed to be 3 to 4 times faster than the forward travel.
- It should provide a fairly wide range of variable speeds.
- It should be possible to stop the running table suddenly, whenever desired for any purpose, and restart it instantaneously.
- It should incorporate a mechanism for speed reduction.

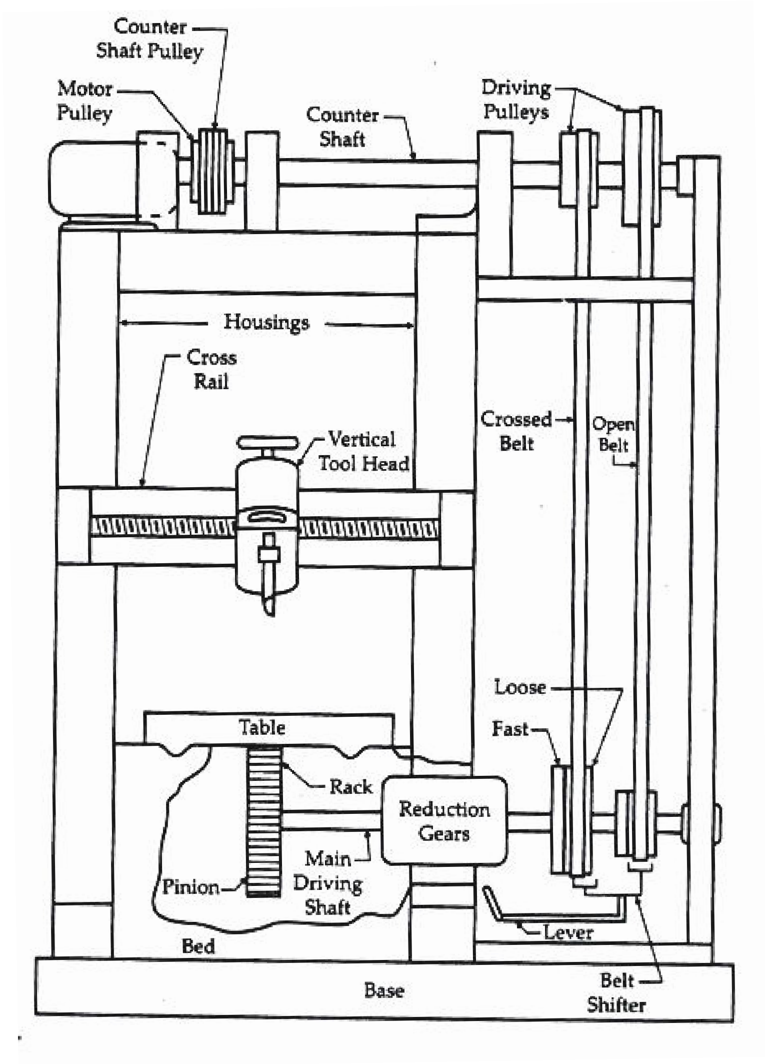
Quick Return Mechanisms for Planer Tables

The common methods used for providing a Quick return motion to the machine table are the following :

1. Belt Drive

Most of the common types of planers carry this system of drive for the Quick return of their tables. The main features of this drive are shown in Figure. It consists of the main driving motor situated over the housings. This motor drives the countershaft through an open V-belt. The countershaft at its extreme, caries two driving pulleys; one for open belt and the other for cross belt.

The main driving shaft is provided below the bed. One end of it passes through the housing and carries a pinion, which meshes with the rack provided under the table of the machine, as shown. The other end of this shaft carries two pairs of pulleys-each pair consisting of a fast pulley and a loose pulley. One of these pairs is connected to one of the driving pulleys by means of an open belt and the other to the second driving pulley by means of a cross belt. A speed reduction gear box is mounted on the main driving shaft and the same is incorporated between the pinion and the pairs of driven pulleys, as shown in the diagram.



One set of the above pulleys is used for the forward motion of the table and the other set for backward or return motion. In the given diagram, the cross belt will be used for forward motion and the open belt for return motion. Note that the driving pulley on the countershaft for cross belt is smaller than the pair of fast and loose pulleys for the same. Against this, the driving pulley on the countershaft for open belt is bigger than the pair of fast and loose pulleys for the same. Consequently, therefore, for same speed or number of revolutions of the countershaft the main driving shaft will turn faster when connected by open belt than when the cross belt is used. It is obvious, therefore, that the return stroke will be faster than the forward stroke.

It should also be noted here that the pulleys are so arranged that when the cross belt is on the fast pulley, i.e., in forward stroke, the open belt will be on the loose pulley and its reverse will take place during the return stroke. In order that this relative shifting of belt may take place automatically at the end of each stroke, without stopping the machine, a Belt shifter and its operating lever are provided on the machine trip dogs are mounted, on each at both ends, on the table. At the end of each stroke, these dogs strike against the operating lever alternately and the belt shifted accordingly. Thus, the table movement is reversed automatically.

Direct Reversible Motor Drive

A large number of Modern planers carry this system of table driving and reversing. In this, a D.C. Reversible motor is directly coupled to the main driving shaft. The direction of rotation of this motor can be instantaneously changed by reversing the polarity. This is done by operating two different switches, which are actuated by means of the trip dogs provided at each end of the table. Also, the speed of this motor can be controlled by varying the supply of the electric current in the field.

A very popular Electric Drive, which is very widely used in a majority of modern planers, is Ward-Leonard Drive. This type of reversible drive is highly popular in modern planers because of its capability of reversing the table movement almost infinite times without losing its reliability and flexibility. This drive mainly consists of an A.C. Induction Motor, a D.C. Generator and a Variable speed Reversible D.C. motor. The A.C. motor is driven by the power obtained from the mains supply. This motor drives the D.C. Generator which, in turn, drives the variable speed D.C.motor. Variation in the speed of the D.C. motor can be affected by:

(i) Changing the excitation of D.C. motor or,

(ii) Changing the armature voltage supply.

The D.C. motor is connected to the table drive gear mechanism through the speed reduction gears to transmit motion to the table. The reversal of the table travel at the end of each stroke is affected by trip dogs, which change the direction of current through a change in the field of Generator and, hence, the direction of rotation of the D.C. motor.

Some common advantages of using an Electric Drive are:

- It is safer than Belt drive.
- A wider range and larger variation of cutting speeds is possible.
- The return speed of the table can be made much faster and, hence, a lot of saving of time can be affected.
- Its control is easier, safer, faster and more accurate.

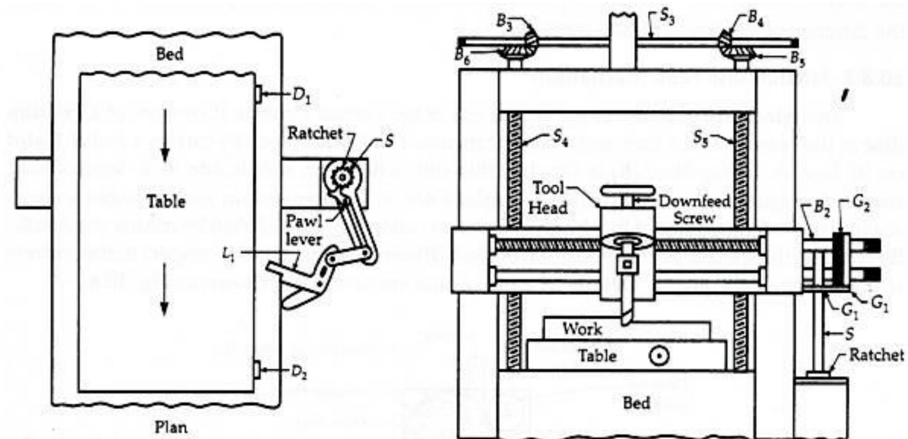
Feeding Mechanisms

In a planer, the horizontal feed to the tool is given by moving the tool head along the cross rail and vertical feed, to vary the depth of cut, is imparted by moving the vertical slide of the tool head by means of the down feed screw. Both power and manual feeds can be employed, as desired. The following three types of feed mechanisms are commonly used in a planer :

- Ratchet and Pawl Feed Mechanism.
- Friction Disc Feed Mechanism.
- Electrical Feed Mechanism.

Ratchet and Pawl Feed Mechanism

It is a common feed mechanism on planers and is shown in Fig.10.7. It mainly consists of a Ratchet and a pawl, mounted on a shaft, which is connected to the Feed shaft, Cross feed screw and the Down feed shaft by means of gearing at its upper end. The mechanism is mounted on the bed on one side of the vertical column.



Plan
(Cross Rail and Other Top Parts Removed)

Elevation

In the given figure, the Table is shown in its forward or idle stroke. At the end of the stroke, the trip dog D_1 will strike against the Lever L_1 making the pawl to push the Ratchet forward, as shown. Since the ratchet is mounted on the shaft S, the latter rotates along with the former. This in turn, imparts power to the cross-rail screw S_1 through bevel gears B_1, B_2 and spur gears G_1 and G_2. Screw S_1 works inside a nut provided at the rear side of the Tool head and that causes the tool head to move horizontally. This movement or horizontal feed is even at the end of each idle stroke. At the end of backward or cutting stroke of the table the trip dog D_2 strikes against the lever L_1 to bring it to the former position.

For giving automatic vertical feed, the feed shaft S_2 of the cross-rail is used. For this, the gear G_2, instead of being fitted on screw S_1 can be fitted on feed shaft S_2 and the power will now be transmitted to S_2 instead of S_1 shaft S_2 is connected to the tool head slide through bevel gears. The slide, thus, moves vertically. Alternatively, the gear G_2 may be put out of mesh with gear G_1 and the latter put in mesh with another gear fitted separately on S_2. Rest of the operation is the same.

Sometimes a large amount of vertical movement of the tool is required particularly when jobs of different heights are to be accommodated. For this, the cross rail is to be moved up or down along the column ways. For moving the cross-rail, the shaft S_3 is rotated by means of a handle fitted at its end. This, in turn, rotates the screws S_4 and S_5 through bevel gears B_3, B_4, B_5 and B_6. These screws work inside the nuts provided at the back of the cross-rail. As the screws rotate at their respective positions the cross-rail is moved up or down according to the direction of rotation of these screws.

Metal Cutting and Machine Tools

UNIT - V

Objective:

- To familiarize with the working principles of Drilling and Boring Machines.
- To impart knowledge on Types, operations performed and the tools used on above machines.
- To familiarize with the working principle of Milling Machine.
- To impart knowledge on Types of milling machines, operations performed, milling cutters and attachments used on above machine.

Syllabus

Drilling and Boring Machines & Milling Machine: Drilling principle of working, specifications, types, operations performed, machining time calculations.
Boring Machines: Principles of working, specifications, operations performed, Boring Machines-types
Milling Machine: Principle of working, specifications, types, operations performed types of cutters, methods of indexing.

Learning Outcomes:

Student will be able to

- Use the working principles of drilling and boring machines in hole making process
- List the different types of drilling and boring machines.
- Identify suitable operations performed on drilling and boring machines.
- Differentiate drilling, reaming and boring operations.
- Calculate the cutting speed and machining time to perform variety of operations.
- Use the working principle of milling operation in performing milling, cutting, planning, key cutting, slot cutting etc., operations
- List the different types of milling machines.
- Identify suitable operations performed on milling machines.
- Differentiate up milling and down milling.
- Describe the nomenclature of milling cutter.
- Calculate the cutting speed and machining time to perform variety of operations.
- Compute the crank movement to divide the periphery of work into any number of equal parts.

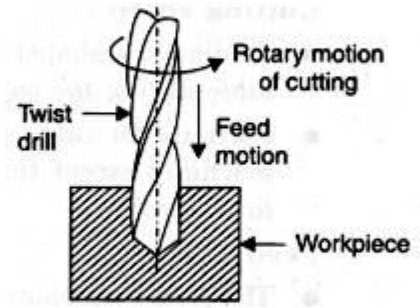
Drilling Machine

Introduction

Drilling is an operation through which holes are produced in a solid metal by means by Drilling, it is considered as a roughing operation. Obviously, therefore, where a very close dimensional accuracy is to be maintained, this forms only the basic operation. For such holes, drilling is followed by another operation called reaming, in which the required dimensional accuracy and fine surface finish are obtained by means of a multi-tooth revolving tool called reamer. Boring is the operation employed for enlarging an existing hole. The hole may be previously drilled, cast, punched or produced through any other suitable operation.

The operations of drilling, boring and reaming can be performed in many ways. They can be done both by hand feed as well as power feed on a large number of machines such as centre lathe, drilling machine, boring machine, capstan and turret lathes, automatic lathe, portable machines and sometimes on special purpose machines.

Working Principle



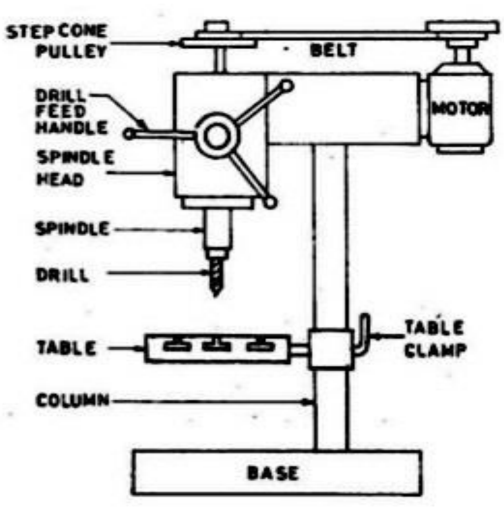
- Drilling is a process of making hole or enlarging a hole in an object by forcing a rotating tool called “Drill”.
- The drill is generally called as ‘twist drill’, since it has a sharp twisted edges formed around a cylindrical tool provided with a helical groove along its length to allow the cut material to escape through it.
- The sharp edges of the conical surfaces ground at the lower end of the rotating twist drill cut the material by peeling it circularly layer by layer when forced against a workpiece.
- The removed material chips get curled and escape through the helical grooves provided in the drill.
- A liquid coolant is generally used while drilling to remove the heat of friction and obtain a better finish for the hole.

Specifications of a Drilling Machine

A drilling machine is specified as follows:

- Size of the drilling machine table.
- Largest bit the machine can hold.
- Maximum size of the hole that can be drilled.
- Maximum size of the workpiece that can be held.
- Power of the motor, spindle speed or feed.

Parts of a Drilling Machine



A power operated machine tool which holds the drill in its spindle rotating at high speeds and when manually actuated to move linearly simultaneously against the workpiece produces a hole is called drilling machine. Figure shows a schematic view of a commonly used standard drilling machine. It consists of the following parts.

Base: The base is of heavy casting made up of cast iron. It supports the column and other parts of a machine.

Column: The column is a vertical upright cylinder, firmly attached to the base. It supports the table, spindle head, motor and the driving mechanism.

Table: It is attached to the column by a clamp. It supports the workpiece and the work holding devices. The table can be moved up and down and can also be rotated around the column. It can also be fixed at the desired position using the clamp. It has T-slots for clamping the workpiece.

Spindle Head: The spindle head is mounted at the top of the column. It has drive motor on one side and spindle assembly on the other side.

Drive Mechanism: The motor drives the spindle through a V belt and stepped cone pulley. By shifting the V belt from one pulley step to another, spindle speeds can be changed.

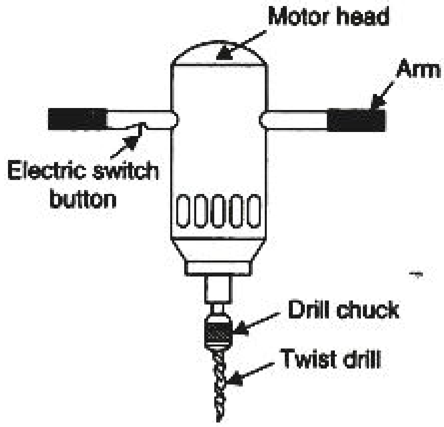
- Drilling machine is one of the simplest, moderate and accurate tool used in production shop and tool room.
- In operation, spindle which imparts rotary motion to the drilling tool, or mechanism for feeding the tool into the work, a table on which the work rests and a frame.
- It is considered as a single purpose machine tool since its chief function is to make holes.
- However, it can and does perform operations other than drilling also.

Types of Drilling Machines

Drilling machines are manufactured in various sizes and varieties to suit the different types of work. They can, however, be broadly classified as follows:

1. Portable drilling machine.
2. Sensitive or bench drilling machine.
3. Upright drilling machine.
4. Redial drilling machine.
5. Gang drilling machine.
6. Turret machine.
7. Deep hole drilling machine.
8. Multiple spindle drilling machine.
9. Automatic drilling machines.

Portable Drilling machine



- Refer to Figure, portable drilling machine is a very small, compact and self contained unit carrying a small electric motor inside it.
- It is very commonly used to drill holes in the following cases: (i) when the component is bigger in size such that it cannot be shifted to the shop floor; (ii) when the space is restricted so that no other type of drilling machine can be used.
- Usually they are made to hold drills upto a maximum diameter of 12mm. However, portable drills of upto 18mm dia. Capacity are available.

Sensitive or bench drilling machine

These are light duty machines used in workshops. They are normally mounted on work benches and hence the name. As the operator can feel the cutting operation while applying pressure using the feed lever, the machine is known as sensitive drilling machine.

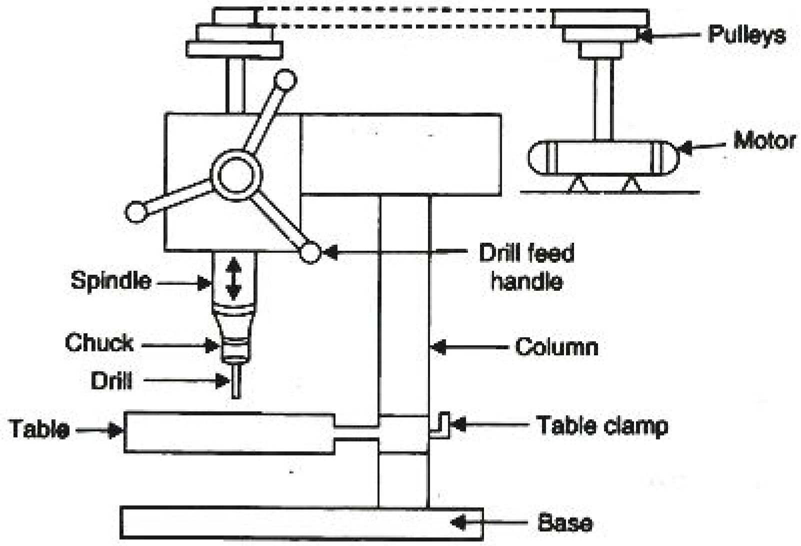
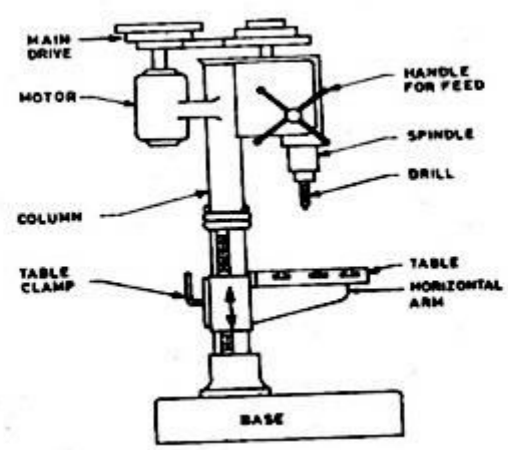


Fig. 9.73. Sensitive or bench drilling machine.

- It consists of a cast iron base with a vertical column mounted over it.
- The vertical column is made of hollow steel pipe on which the table slides up and down.
- The table can be fixed to the required position by means of a table clamp. The table can also be swung radial at any desired position.
- The top of the column houses the drive consisting of endless belt running over the V-pulleys.
- Based on the speed of spindle required, V-belt can be shifted to different grooves of the pulleys.

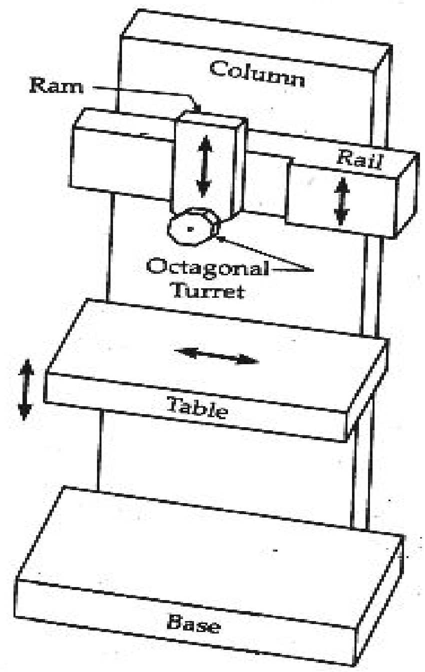
- To drill small diameter holes, a twist-drill is fitted in the drill chuck, which in turn fits into the spindle of the machine.
- If the drill size is more, twist drill is directly fitted in the tapered portion of the spindle.
- The spindle can be moved up or down by means of drill feed handle or lever.
- This design is used to drill hole from 1.5mm to 15mm diameter.
- The controls are light and delicate speeds from 800 to 900 r.p.m are typical range.

Upright Drilling Machine (Single Spindle)



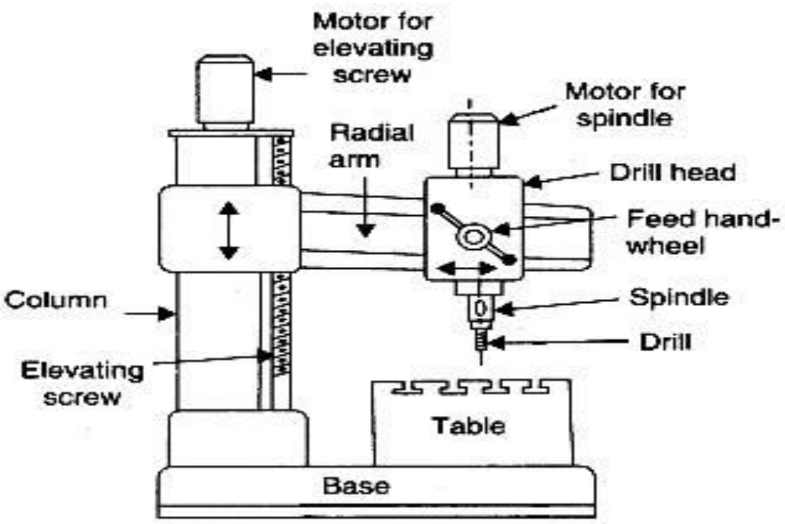
- A typical upright drilling machine is shown in Figure.
- It is also known as standard, vertical or pillar drilling machine.
- It is used for heavier work and has back gearing arrangement similar to a lathe.
- It specifically differs from a sensitive drill its weight, rigidity, application of power feed and the wider range of spindle speeds.
- The vertical column can be either round or box type. Box type column is usually provided when the machine is constructed for relatively heavier work.
- These machines are manufactured in various sizes having different Drilling capacities up to a maximum of 75mm is steel. The most commonly used size is 38mm in steel.
- If needed, a reverse motion can be incorporated for tapping work.
- A cylindrical vertical pillar facilitates the swinging of table to any position and, in combination with the rotary movement of the table, it enables any part of the surface to come under the tool without disturbing the work.
- If a box type rectangular pillar is used, vertical slides or ways are provided to enable similar settings.

Upright Drilling Machine (Turret Type)



- It is production drilling machine, which is very useful when a series of different size holes are to be drilled repeatedly or a number of different operations, like drilling, reaming, counter boring, countersinking, spot facing, etc., are to be performed in sequence repeatedly.
- The main parts of the machine, as shown by means of a block diagram in figure, include heavy base, vertical column, a Ram carrying turret head and a table.
- The table can be raised or lowered along the column. Also, it can be moved longitudinally sideways and across to bring the job in correct position below the tool.
- The turret head, which carries six, eight or ten different tool mounting positions, is mounted on a ram.
- It can be easily indexed to bring the proper tool in operating position over the work and can be raised or lowered by moving the ram upwards or downwards.
- The required tools are mounted in sequence in the turret head so that they automatically come in operating position when the head is indexed.
- This type of machine eliminates tool changing time and a single machine can be used to perform a number of different operations one after the other.
- The smaller varieties of these machines are usually manually operated, but a large variety of these machines is numerically controlled (NC) type.

Radial Drilling Machine



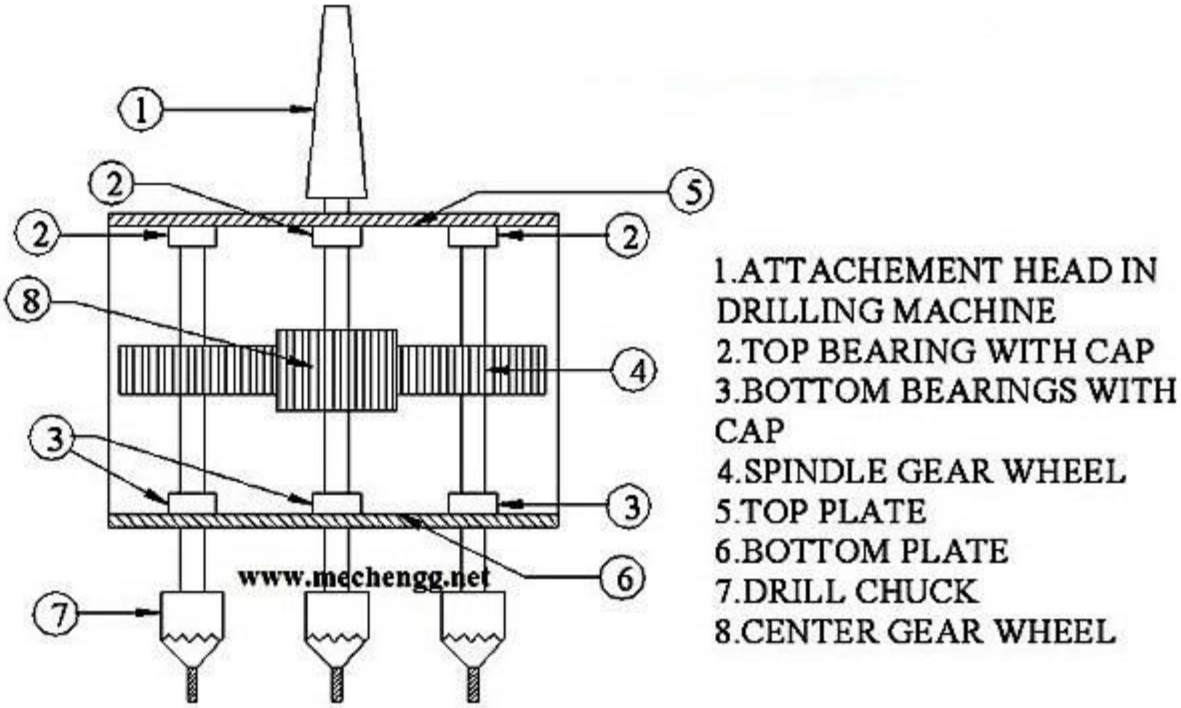
- A Radial drilling machine is used to perform the drilling operations on the workpieces which are too heavy and also may be too large to mount them on the worktable of the vertical spindle drilling machine.
- It consists of a heavy base and a vertical column with a long horizontal radial arm extending from it and can be rapidly raised lowered and swing in horizontal plane about the main column to any desired location.
- The drilling head can move to and from along the arm and can be swivelled only in the universal radial drilling machines, to drill holes at an angle.
- The combinations of motions of the radial arm and drilling head offer a great deal of flexibility in moving the drill to any position.
- The main advantage of the radial drilling machine is that the drilling can be carried out on heavy workpieces in any position without moving them.
- This type of drilling machine is used in tool rooms and in large scale die manufacturing units.
- Based on the type and number of movements possible the Radial Drills can be broadly grouped as:

  1. Plant Radial Drills. Three principal movements are possible in this type of machine, viz., Vertical movement of the Arm along the Column, horizontal Sliding movement of the Drilling Head or Spindle Head along the Arm and Radial Swinging of the Arm in a horizontal plane.

  2. Semi-Universal Radial Drills. These machines, in addition to the above three basic movements, carry provision for swinging of the spindle Head about a horizontal axis which is normal to the arm. Thus, the Head, and hence the spindle, can be inclined to a suitable angle with its normal vertical position on either side, enabling drilling of holes at desired inclinations with the normal vertical position.

  3. Universal Radial Drills. In this machine the arm itself can be rotated through a desired angle along a horizontal axis. This is in addition to the four possible movements available on a Semi-universal Machine. This makes this machine highly versatile and facilitates drilling at any desired inclination and location.

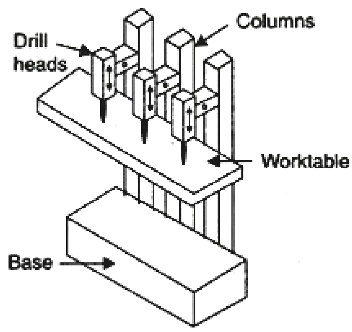
Multi Spindle Drilling Machine



- These machines are mostly used in production work and are so designed that several holes to different sizes can be drilled simultaneously.
- Their use facilitates an increased rate of production with sufficient accuracy.
- In these machines two or more spindles are driven from a common driving shaft through worms and worm gears or belts. Each spindle carries a Universal Joint.
- The table may be of fixed type or adjustable type. The former type is commonly used.
- In some machines a Cross-rail is provided, along which the vertical spindles can be moved horizontally to set them at a desired distance apart.
- In Universal type of these machines, the spindles are mounted on a common Head which carries a central gear.
- Each spindle carries a pinion at its upper end which meshes with the central gear, which acts as the driving gear for all these pinions.
- In this way, all the spindles receive power simultaneously from the same central gear. This mechanism is quite similar to that used for driving the spindles of a multi-spindle automatic lathe.
- Two other types of Heads are also used, one is known as Adjustable Head and the other as Gearless Head.
- Drill heads with a capacity of drive upto 50 spindles simultaneously are available. In these heads it is possible to adjust the spindles to adjust the spindles to several different positions to enable drilling of holes at any location within the area covered by the head.
- However, for efficient and accurate production of holes a properly designed drill Jig is normally used for each component to guide the drills accurately.

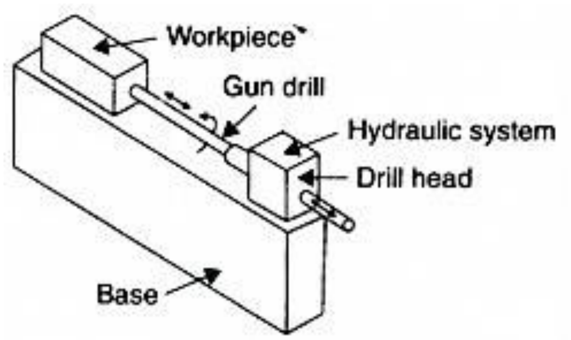
Gang drilling machine:

- When several drilling spindles are mounted on a single table, it is known as a gang drill.
- In this type of drill, each of these spindles can be independently set for different speed and depth of cut.



- Such machines are useful when numbers of holes of different sizes are to be drilled on the same workpiece.
- Apart-from drilling, a number of other machining operations like reaming, counter boring, tapping etc; can also be performed at a time on this machine.

Deep-hole drilling machine



- These machines are used for drilling holes whose depth exceed normal drill size.
- These machines are operated at high speed and low feed.
- These machines are either horizontal or vertical.
- The work or the drill may revolve.
- Most machines are of horizontal construction using a centre-cut gun drill, which has a single cutting edge with a straight flute running throughout its length.
- Oil under high pressure is forced to the cutting edge through a lengthwise hole in the drill.
- In gun drilling the feed must be light to avoid deflecting the drill and causing it to meander through it length.
- These machines are very useful for drilling deep holes in rifle travels, crankshafts etc.

Horizontal Drilling Machines

All the drilling machines, except one variety of deep hole drilling machines, are of vertical type, i.e., they carry their spindles in a vertical direction, and consequently the drill (tool) is held vertically in them. There are, however, some special purpose machines, though not so common in use as vertical drilling machines, in which the spindle remains horizontal and so remains the tool. These machines are mainly employed for long jobs, such as columns, Pipes and Barrels, etc which are difficult to be drilled in vertical position. Also, for such objects which, due to their excessive weight or extraordinarily large size, cannot be handled easily, the operation of drilling has to be performed by keeping the job stationary and moving the machine around them. Such jobs require the use of horizontal machines. The machines for such jobs carry several movable columns which operate on different positions on the job simultaneously. The job is marked and the machines set before the operation starts. Suitable jigs and fixtures are usually designed and used for this purpose.

Automatic Drilling Machines

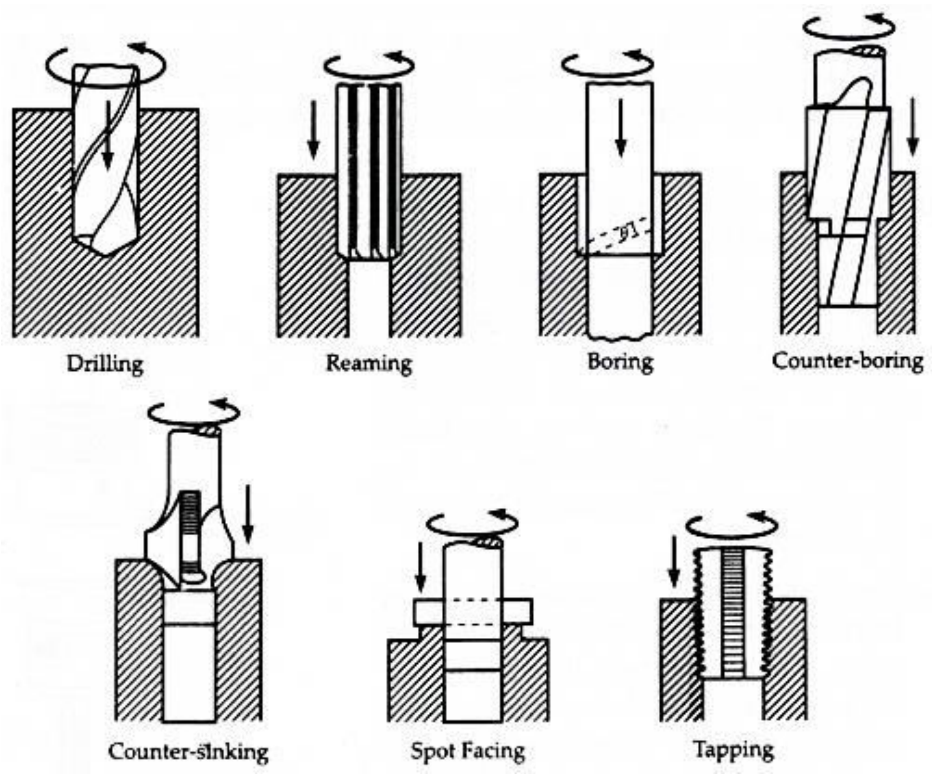
These are production machines, arranged in series to perform a number of different operations in sequence at successive work stations. The workpieces, after completion of an operation at one station, are automatically transferred to the next station for another operation.

Thus, it works as a transfer line. The operation sequence, related cutting speeds and feeds, start and finish of the operation on each station, etc, are so arranged and synchronised that, once the workpiece is loaded at the first station, it automatically switches on to the next position for the next operation till it undergoes the last operation and unloaded. The spindle heads may carry a single spindle each, multi-spindles or a combination of these, according to the requirements. Each work station may carry an indexing table and suitable work-holding fixtures. Several different operations like drilling, boring, tapping, Milling, Honing, etc., can be performed on a job in succession on these machines.

Operations Done On Drilling Machines

There are a number of operations done on a drilling machine, as shown in Figure. These are as follows:

- Drilling
- Boring
- Counter-sinking
- Tapping
- Reaming
- Counter-boring
- Spot facing, and



Drilling**:** It is the main operation done on this machine. It is the operation of producing a circular hole in a solid metal by means of a revolving tool called Drill.

Reaming**:** It is the operation of finishing a hole to bring it to accurate size and have a fine surface finish. The operation is performed by means of a multitooth tool called reamer. The operation serves to produce a straight, smooth and accurate hole. The accuracy to be expected is within ±.005 mm.

Boring**:** It is an operation used for enlarging a hole to bring it to the required size and have a better finish. It involves the use of an adjustable cutting tool having a single cutting edge. In addition to the above objective, this operation can be used for correcting the hole location and out of roundness, it any, as the tool can be adjusted to remove more metal from one side of the hole than the other. It is a slower process than reaming. The accuracy to be expected is within ±.0125mm.

Counter-boring**:** The operation used for enlarging only a limited portion of the hole is called counter-boring. It can be performed either by means of a double- tool boring bar or a counter-boring tool. In order to maintain alignment and true concentricity of the counter bored hole with the previously drilled hole the counter boring tool is provided with a pilot at its bottom, as shown.

Counter-sinking**:** It is the operation used for enlarging the end of a hole to give it a conical shape for a short distance. This is done for providing a seat for the countersunk heads of the screws, so that the latter may be flush with the main surface of the work. The standard counter-sinks carry included angles of 60°, 82° or 90°.

Spot Facing**:** This operation is used for squaring and finishing the surface around and at the end of a hole so that the same can provide a smooth and true seat to the underside of bolt heads or collars, etc. This is usually done on castings or forgings. The hole may be spot faced below the rough surface or above it, i.e., on the upper surface of the boss, if the same is provided.

Tapping**:** It is the operation done for forming internal threads by means of the tool called tap. To perform this operation, the machine should be equipped with a reversible motor or some other reversing mechanism. Alternatively, a collapsible type tapping attachment shown in figure can be used.

Tap Drill Size

For tapping, the size of the hole to be made through drilling has to be smaller than the size of the tap. It is because the tap size is equal to the outside diameter of the threads whereas the size of the drill to be used before tapping should be equal to the core diameter of the threads.

The drill size can be calculated as follows:

Drill size = Tap Size – 2 × Depth of threads.

For common usage the approximate Tap-drill size can also be found out from the following imperial rule :

Drill size = 0.8 × Tap size.

The result obtained from this relation holds good for most of the cases because the threads work quite satisfactorily even if their three-fourth depth has been achieved.

Cutting Speeds, Feeds and Depth of Cut

The cutting speeds and feeds in drilling, as in case of other machines, depend upon many factors like material to be cut, material of tool type of finish required, type of coolant used, capacity of machine and the tool life, etc. The amount of feed per revolution usually varies between .05 mm to .38 mm upto 25 mm dia. Drills. The spindle speed in r.p.m. can be calculated from the formula :

$$r.p.m = \frac{Cutting\ speed\ in\ meters\ per\ minute}{\pi \times Drill\ dia, in\ meters}$$

$$= \frac{Cutting\ speed\ in\ mpm \times 1000}{\pi \times d}$$ [where d=drill dia in mm]

Also, cutting speed (S) is given by

$$S = \frac{\pi d N}{1000} mpm$$

where, d=drill dia. in mm and, N=spindle speed in rpm.

From the above relation it is clear that for the same peripheral speed (S), the smaller the drill dia (d) the more will be the rotational speed (N), i.e, a smaller drill will rotate at a faster rate than a larger drill in order to maintain the same cutting speed. Also, there is a gradual variation in the cutting speed from 'zero' at the centre to the maximum at the periphery.

Example: A hole of 20 mm dia. is to be drilled through a mild steel plate 16mm thick. Calculate the r.p.m. of the drill spindle when the cutting speed is 26 meters per min.

Solution: $N = \frac{V \times 1000}{\pi d} = \frac{26 \times 1000}{3.14 \times 20} = 414\ r.p.m$

Feed

It is the distance a drill moves, parallel to its axis, into the work in each revolution of the spindle. It is expressed in mm per revolution. If the total distance moved by the drill into the work, parallel to its axis, in one minute is considered, it can be expressed as feed in mm per minute. Now, if N be the No. Of revolutions made per minute by the drill, then :

Feed in mm/min = Feed in mm/rev.×N

The following factors govern the amount of feed to be provided:

- Workpiece material
- Depth of drilling
- Range of available feeds
- Rigidity of the machine
- Degree of surface finish required
- Horse power of the motor
- Drill size.

Depth of Cut

In drilling operation the depth of cut is measured at right angles to the axis of the drill, i.e, the direction of feed, and is numerically equal to one-half of the diameter of the drill. It can be expressed as :

$$Depth\ of\ cut = \frac{Depth\ dia.}{2} mm$$

Example : At what speed a 15mm dia. drill will run, to drill a hole through a brass plate 20mm thick, in order to cut the material at a surface speed of 60 m.p.m. also calculate the feed used, per rev.

$$Solution. \quad N = \frac{V \times 1000}{\pi d} = \frac{60 \times 1000}{3.14 \times 15} = 1273\ r.p.m.$$

and, $Feed = \frac{Total\ distance\ moved\ axially}{r.p.m}$

$$= \frac{Plate\ thickness + 0.3d}{r.p.m} = \frac{20 + 0.3 \times 15}{1273}$$

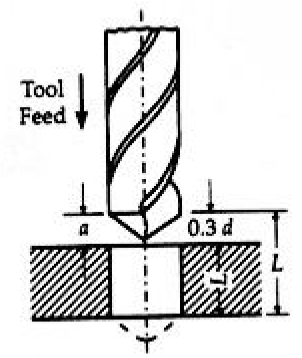
$$= \frac{20+4.5}{1273} = \frac{24.5}{1273} = 0.02\ mm\ per\ rev.\ (approx.)$$

Estimating Machining Time

In drilling operation, the Machining Time is given by

$$T = \frac{L}{N \times f}\ min$$

Where N = rpm of drill
L = Length of axial travel of drill in mm
f = feed per rev. in mm
T = machining time in min



Now L = *l*+*a* (See Fig.)
Where *l* = depth or thickness of workpiece
A = approach of drill = 0.3d
d = diameter of drill

Example: Calculate the machining time for drilling 4 holes of 16 mm dia. each on a flange from the following data. Flange thickness=30 mm; cutting speed = 22 mpm, Feed=0.2 mm/rev.

Solution: $N = \frac{Cutting\ speed \times 1000}{3.14 \times d} = \frac{22 \times 1000}{3.14 \times 16} = 438\ r.p.m.$

For one hole; $T = \frac{L}{N \times f} = \frac{30+0.3 \times 16}{438 \times 0.2} = \frac{34.8}{87.6}\ min$

$$\therefore for\ 4\ holes, \quad T = \frac{4 \times 34.8}{87.6} = 1.47\ min.$$

BORING

Introduction

The operation of Boring differs from Drilling in that it implies the enlargement of an or Forging. When small holes are to be bored. Particularly in small jobs, which can be conveneienty held in Chucks or Face plates, the operation of Boring can easily be done on centre lathes or capstan and turrets of medium size. For large and heavy jobs, special boring machines are to be used, which make the operation easy and efficent. These machines are, however, production machines and their use is normally confined to those shops where their existence is justified by the need for boring on a large scale.

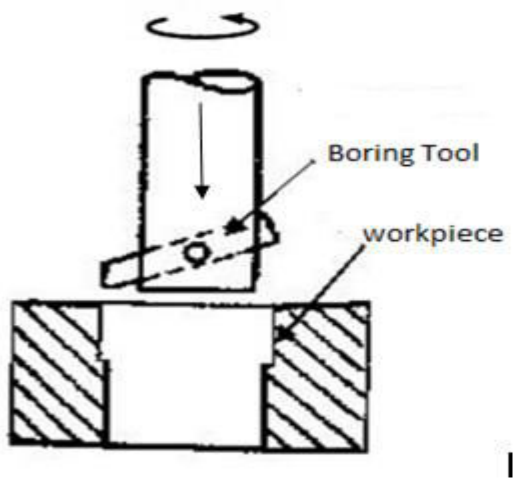
Boring is the process of using a single point tool to enlarge and locate a preciously made hole. Drills tend to wander or drift, thus, where greater accuracy is requuired, drilling is followed by boring and reaming.

- Beside enlarging previously made holes, a boring machine can be used for drilling, facing, milling etc.
- Boring machines are one of the largest of the machine tools and are able to machine workpiece wieghing upto 180kN.

Working Principle

- The boring tool for a boring machine is usually a single point cutting tool made of HSS or carbide and is mounted on the tool head. It is capable of vertical movment and radial movement guided by the cross rail. The head can be swivelled to produce tapered internal surfaces or taper boring.

  The boring is a cutting operation that uses a single-point cutting tool or a boring head to produce conical or cylindrical surfaces by enlarging an existing opening in a workpiece.



Specifications of Boring machine

Machine Size of Horizontal Machines

The size of a Horizontal Boring machine is designed by the maximum diameter of the Boring Bar it can hold. The common sizes vary from 75 mm to 350 mm. Other main details to specify a Boring Machine fully include the following:

- Type of Machine.
- Maximum travel of the Spindle.

- Maximum travel of Table in longitudinal and cross direction, if it is a Table type machine.
- Spindle speeds and feeds.
- Maximum allowable weight of work piece. It is a significant factor in case of those machines in which the work moves.
- Power of Electric Motors.
- Heights of Columns.
- Size of Table or Floor Plate, as the case may be.
- Gross Weight of the Machine.
- Floor Space required.

Classification of Boring Machines

Boring machines are manufactured in various designs and sizes. They can be broadly be classified as follows :

1. **Horizontal boring machines (HBM)**
   (i) Table type HBM
   (ii) Planer type HBM
   (iii) Floor type HBM
   (iv) Multiple spindle HBM.
2. **Vertical boring machines**

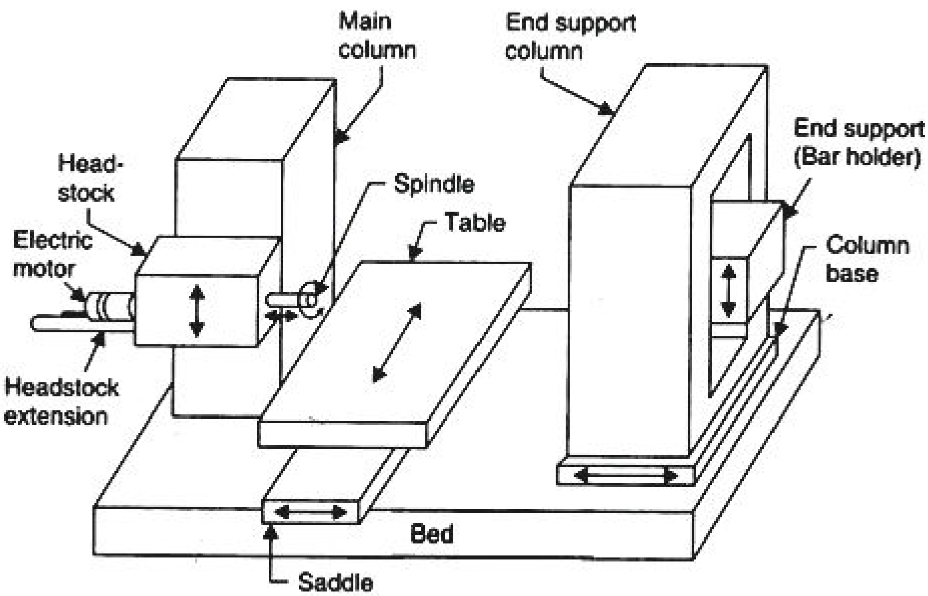
   } *... Production machines*

3. **Jig boring machines** ……… Pricision machine used for precision boring operations such as Jig boring.

Horizontal Boring Machines -

i) Table Type HBM

The table type or universal type is the most versatile and commonly used horizontal boring machine. Figure shows the block diagram of a horizontal boring, drilling and milling machine. The principal features of this machines are,



Bed

- It is a heavy Cast Ironstructure and is the main supporting member of the machine.
- It supports and links all the other units of the machine.
- It has a closed box shaped cross-section and carries wide Gujideways at its top.

- The walls are adequately reinforced by means of a number of cross and longitudinal Stiffening Ribs.
- A separate Housing on the right-hand side of the bed, which can be on the left hand side also, as shown in Figure, carries mechanisms for the Vertical traverse of the Headstock and the Longitudinal traverse of the Table.
- Also, it carries a motor for automatic rapid traverse of these units.
- The Column and the Table are mounted directly on the bed ways.
- Various Control levers, shanks and other details are provided on the same side of the bed to affect different traverses of the above units.
- On the left hand side of the bed is provided the End-support column or stay. It is also directly mounted on the Guideways.

Main Column

- It is another sturdy part of the machine which provides support to the complete Headstock Unit.
- At its front, it carries Vertical Guideways, along which the Headstock travels up and down.
- A Counterweight is always necessary to balance the Headstock.
- This weight may be inside or outside the column, but the latter pattern is preferred in order to increase the rigidity of the Column aas it makes room for the stiffening ribs to be provided inside.
- As the Colimn has to carry enough loads during the operation, it is made sufficiently sturdy and robust to ensure adequate rigidity and resistance to vibrations.

Headstock

- It is an independent unit of the machine which carries a number of different mechanisms, interconnected to one another, to enable the different operations to be performed by it.
- The main mechanisms and other devices are the following:
  - a) Main Driving Mechanism.
  - b) Spindle Assembly.
  - c) SpindleTraverse Mechanisms.
  - d) Feed Gear Box.
  - e) Headstock Extension.
  - f) Speed and Feed Changing Mechanisms.
  - g) Turnstile Assembly.
  - h) Clamping Device.
  - i) Oil Pumps

Table and Saddle

- The complete unit consists of two Saddles and a rotary Table.
- Out of the two saddles, the lower one moves longitudinally along the horizontal guideways provided on the bed.
- The upper saddle moves at right angles to the direction of movement of the lower saddle along the Cross Guideways provided on the latter.
- At its top, the upper saddle carries Circular Guideways, along which the rotary table can be rotated and swivelled to any desired position.
- The horizontal traverse of the Lower Saddle, cross traverse of the Upper Saddle and the rotary motion of the Table can all be operated manually or by power, as desired.
- Provision is always made for proper lubrication of all the moving parts.

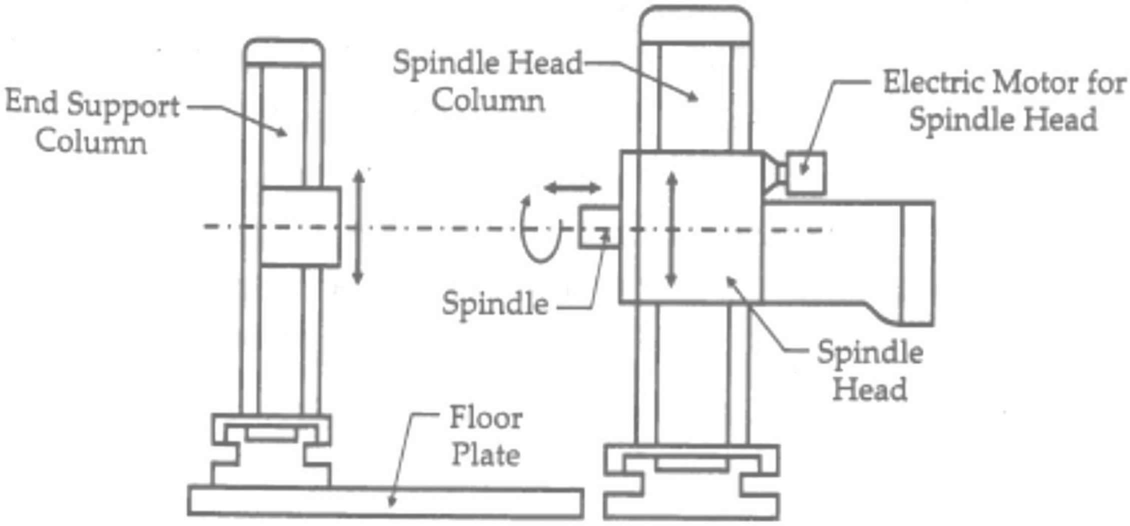
End Support Column or Stay

- It is provided to carry the End support (Bar Holder), as shown.

- At its front it carries vertical guideways along which moves the Bar Holder carrying the Bearing.
- A common Lead shaft is incorporated in the bed which synchronises the vertical movements of the Bar Holder on one side and the Headstock on the other side.
- The use of Bar Holder is taken for supporting the outer end of the overhanging Boring Bar when the overhang is too much, as in case of boringlong holes.
- A Device is fitted to the End Support Column to facilitate an automatic alignment of the axis of the bearing of the Bar holder with that of the Boring spindle.

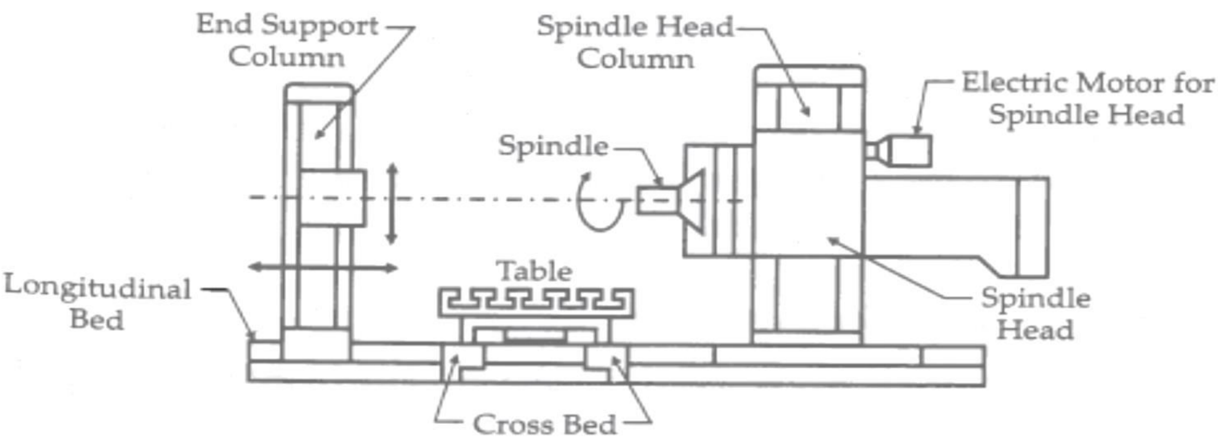
ii) Floor Type Horizontal Boring Machine

- This machine is a comparatively heavier type of Horizontal Boring Machine.
- The operating and spindle supporting units are not mounted on a bed, as in Table type machine described above, but are carried on separate runways which facilitate the movement of these units, together with the spindle, past the work.



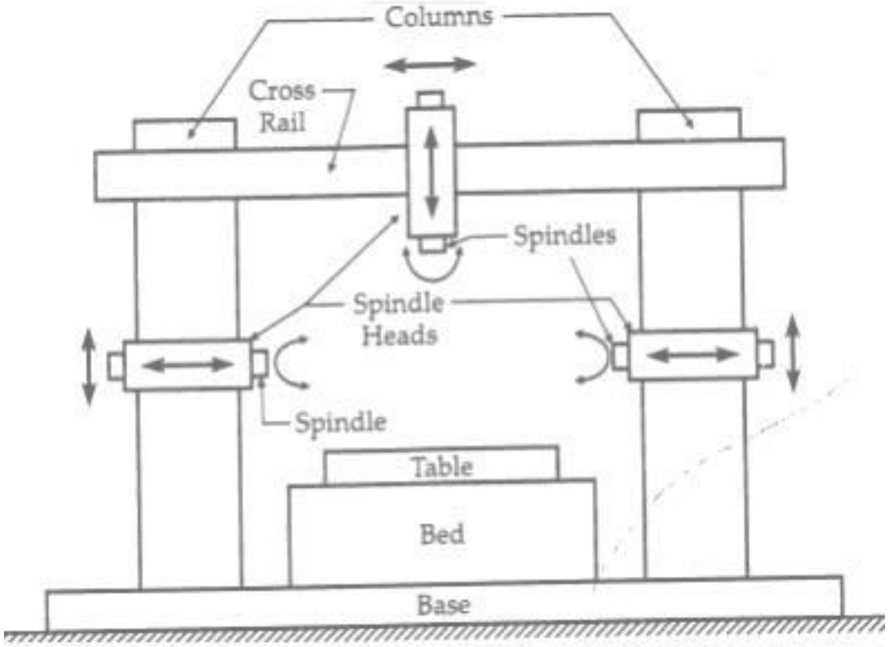
- The work does not move at all, but is kept stationary at a platform called Floor Plate.
- It is this relative movement of work with respect to the other units of the machine in which it differs from Table type Machine (See Figure).
- This type of machine is very suitable for long and heavy jobs, of which frequent manipulation on a table is not easy

iii) Planer Type Horizontal Boring Machine



- This machine resembles in construction with the Table type.
- The only differences is in the construction and operation of the Work Supporting Mechanisms.
- In this, a heavy Cross bed is incorporated between the Spindle Column and the end Support Column.
- The bed is mounted across the axis of the spindle and carries a Table over it. On its two sides it carries the two columns.
- The Main Column, carrying the Headstock, is rigidly fixed whereas the End-support Column can move towards or away from this bed along the horizontal ways provided on the top of the Cross bed, at right angles to the former bed. The job is mounted on the table.
- In operation, it resembles a Planer in that the tool is held between the two columns or mounted on the Headstock only and the work, mounted on the table, moves past the tool. (See Figure).
- This type of machine is very suitable for long jobs.

iv) Multiple Head Type Horizontal Boring Machine



- It consists of two Vertical Columns mounted on the sides of a stationary bed.
- The columns are bridged by means of Cross-rail. As a maximum, four Headstocks can be mounted on the machine, one each on the two vertical colimns and two on the Cross rail.
- The Headstocks on the columns will have Horizontal spindles and those on the Cross rail Vertical spindles.
- In this way, maximum four tools can be mounted simulataneously on this machine.
- The work is mounted on the Table which is supported and moved on the bed.
- In this way, this machine very nearly resembles a Planner type Milling machine.
- The Headstocks can be swivelled to desired angles if angular cuts are required to be taken (See Figure), thus, machining on more than one surfaces on a job is possible simultaneously as upto four tools can operate simultaneously on the job from different angles and at different locations.

Vertical Boring Machines

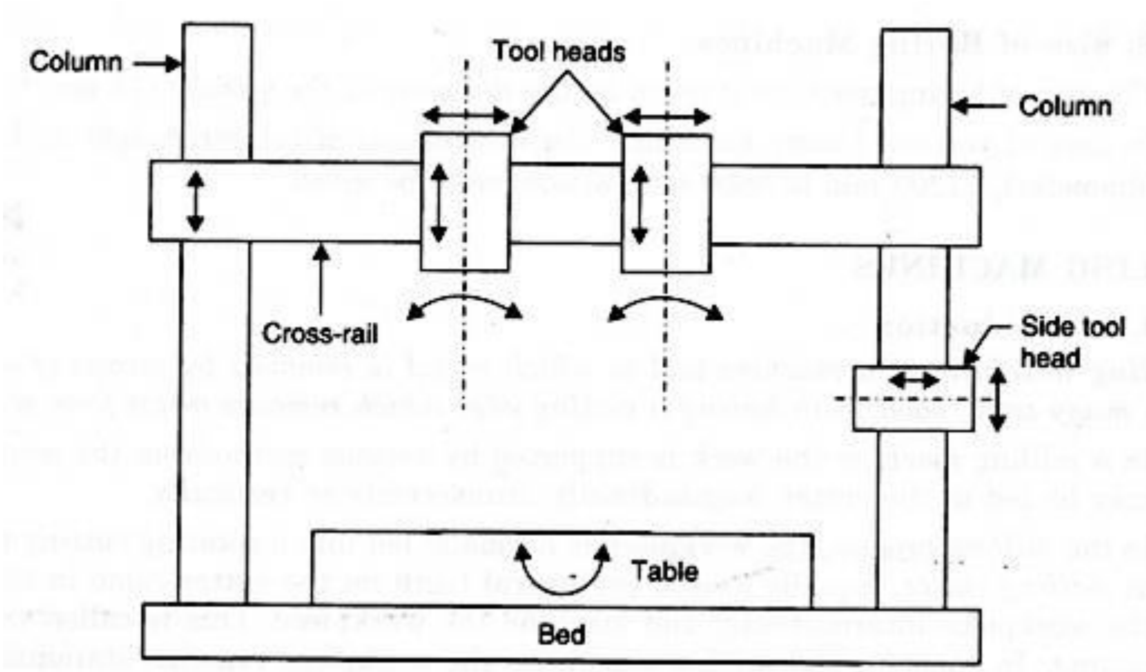
A Vertical Boring Machine is named so because the work held on a rotary table about a vertical axis while the tool(s) remain stationary, except for feeding. The Table, together with the work, rotates in a horizontal plane. Thus, if the table is considered to have replaced the chuck or face plate of a centre lathe, this machine can be considered as a Vertical Lathe with its Bed working as a Headstock.

Mainly the following three types of Boring machines fall in this category:

- Standard Vertical Boring Mills
- Vertical Turret Lathes
- Vertical Precision Boring Machines

All these machines can be used for vertical boring.

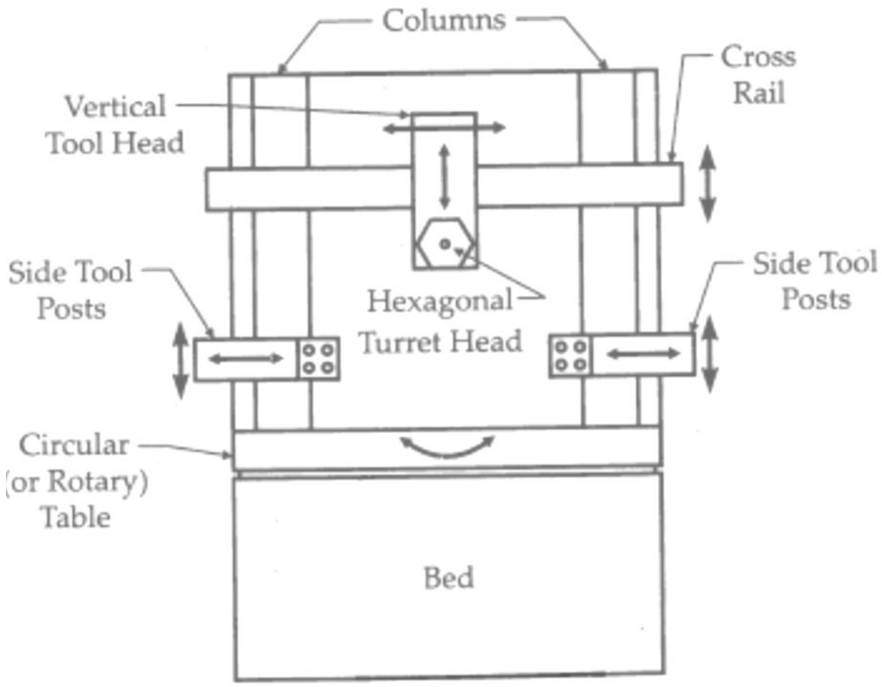
i) Standard Vertical Boring Mill



It consists of a heavy cast iron Bed which carries a Circular Table over it. On the sides of the bed are two Vertical Columns which are bridged together by means a Cross-rail, as shown by means of a block diagram in Figure. As a maximum, four Tool heads can be mounted on the machine, one each on the two Columns and two on the Cross-rail. This number can also be reduced according to the requirements. Usually the Tool heads carry the provision for being swivelled to a certain angle for taking Angular cuts. The Work is mounted on the table which rotates about its vertical axis. The rotating work is, thus, fed against fixed tools, which results in circular cuts being taken on the job. The Table is provided with T-slots for clamping the work.

Usually large and symmetrical workpieces, such as cylindrical objects, are bored on these machines. A few examples are the Casings for steam Turbines, Tables for Machines tools and Pressure vessels. An important point to be noted here is that the Vertical Housings on the two sides of the table limit the size of the work that can be machined on this machine. This maximum size of the work would be nearly equal to the diameter of the machine table and the same will represent the size of the machine. Note that this machine will not undertake oversize work due to the above limitation.

ii) Vertical Turret Lathe



It carries a special advantage that many tools can be simultaneously mounted on the Turret head and, therefore, a large number of different operations can be performed in addition to Boring, in a single setting of work. The table of the machine is of rotary type and carries Adjustable jaws for clamping the work. That is why it is frequently called a Chuck also in this particular case.

The main parts and their possible movements are shown in the block diagram (Figure). The Rotary table rotates over the Bed about a vertical axis. The workpiece is held over this table. Maximum two Slide Tool Posts can be mounted, one each on each column. These Tool posts can be adjusted vertically and they can also move forward and backward. Also, in some designs they can be made inclined. One or two Vertical Tool Heads can be mounted on the Cross-rail, which can be adjusted horizontally along the Cross-rail. Each Vertical Toolhead will carry a Turret Head so as to enable mounting of a number of tools in sequence on it to enable different operations to be performed in a single-setting of tools. The Turret Head can be indexed after each operation to bring the proper tool in position for the next operation. The Vertical Tool Head can also be moved upward and downward according to requirement.

iii) Vertical Precision Boring Machine

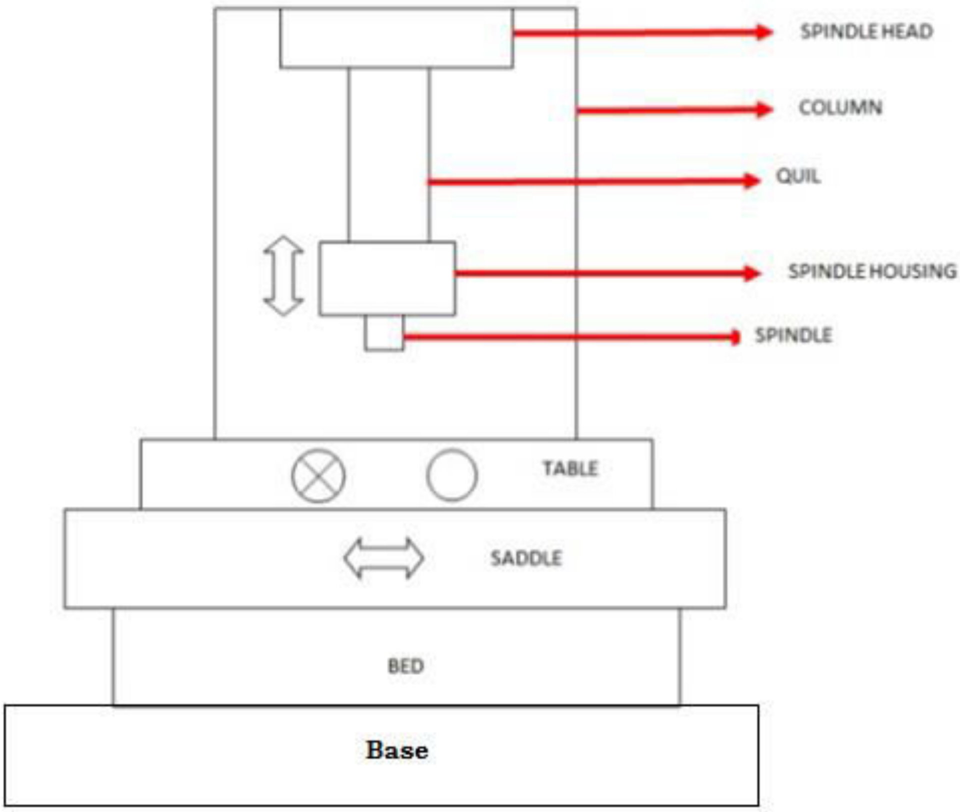
It is a production machine basically designed for boring holes in Cylindrical Blocks and Liners of Automobiles Engines, fine boring of parts in ferrous and non-ferrous metals, etc. In appearance it looks like a jib boring machine, but differs from the latter in that it does not carry the Pick-up Device for coordinate setting.

Salient Design Features of the Machine:

- The machine is convenient in operation and is provided with the necessary interlocking devices, ensuring its operation without breakages.
- The machine is of a highly rigid and vibration-proof design which ensures maintaining its initial accuracy of performance over a long period of time.
- The control of the speed and feed gearbox is conveniently grouped in an easy-to-reach place and is performed by means of three levers.

- Most of the machine units are assembled in independent housings, which considerably facilitate their repair.
- The table, being movable in two directions, permits to bore several holes in a workpiece at one setting.
- The high upper limit of the spindle speed, the ample power of the main drive motor and the rigidity of the machine permit to use the up-to date carbide cutting tools.
- Precision antifriction spindle bearings ensure the machine durability and high accuracy and surface finish.

Jig Boring Machine



A Jig Boring Machine is a specially designed Machine Tool used for precision location and production of holes, as are needed in Jigs, Fixtures, Templates, Dies, Gauges etc. Such a high degree of accuracy is usually called for where the relative location of different holes on the same or adjacent parts affects their operation.

In appearance and construction a Jig Boring Machine resembles very much to a Vertical Boring Machine, but it is comparatively more rigid and accurate than the latter. It machine surfaces rapidly and accurately using cemented carbide and diamond tipped single point cutting tool. It essentially consists of a vertical column and a heavy base on which the bed of the machine is mounted and also supports the other parts of the machine. The column, at its top, carries the spindle head which can slide up and down along the vertical guide ways provided at the front of the former. A saddle is mounted on the horizontal ways on the top of the base to give cross-feed to the work. The table is mounted over the saddle and the same can move to and fro at right angles to the movement of the saddle, along the guide ways provided on the latter the work is, thus, given the longitudinal movement by moving the Table, cross movement by moving the saddle and vertical adjustment of the tool to the work is made by moving the spindle head up or down. A quill is provided in the spindle head and the spindle moves inside it. Spindle and bearings of the machine is constructed with high precision and the work table permits extra precise movement and control. Jig Borers consists of devices with stable and adjustable end gauges and indicator sensing units for precision measurement and location of holes. The machines are installed in insulated areas in which a constant temperature of 20^0 C is maintained. Jig Boring machines are operated by highly skilled workers.

Different Systems of Measurement

There is not much difference among the different types of Jig Boring Machines, though there seem to be so with respect to their designs and sizes. The specific difference, which is of importance, lies in systems of Measurements carried by these machines.
The common systems of Measurements adopted in different Jig Bores are the following:

1. Precision Lead-Screw System

This system consists of a Lead-screw, under the table for moving it, a graduated micrometer dial at its end and a compensating device for corrections in errors in the table movement. The compensating device consists of a profile cam fitted on the side of the table, a lever to follow the cam profile as the table moves and a Link to transfer the variations in the cam to the vernier fitted on the dial of the lead screw. Another similar arrangement is used for cross movements of the saddle. The advantage of this system is that it is enclosed in the machine and is, therefore, not affected by the variations in room temperature. Also, it provides a rapid traverse, but has a disadvantage also in that it limits the size of the table and its travel.

2. End Measure System

'End measures' are nothing but accurately finished rods to Gauge block accuracy. Their lengths are always in even millimetres or inches and the adjustments for decimal fraction are made with the help of Inside micrometers. The end measures and the micrometer and placed in a trough between a Dial indicator on one side and an adjustable stop on the other side on the table. The table is then moved till the dial indicator reads zero. This gives the required location of the hole with respect to two mutually normal finished surfaces. This system is very simple and easy in setting. Also, it does not limit the size of the Machine and the effect of wear is almost negligible, but care should be taken to protect the measures from the effect of temperature vibrations and dirt, etc., as they lie in an open though.

3. Scale and Microscope System

In this system, accurately graduated scales are incorporated in the machine to read the longitudinal movement of the table and the cross traverse of the saddle. These measurements are read through a microscope. The main advantages of this system is that it carries now wearing parts and is free from the effect of dirl, etc., as it is enclosed in the machine. Care should however, be taken to keep it free from the temperature effect.

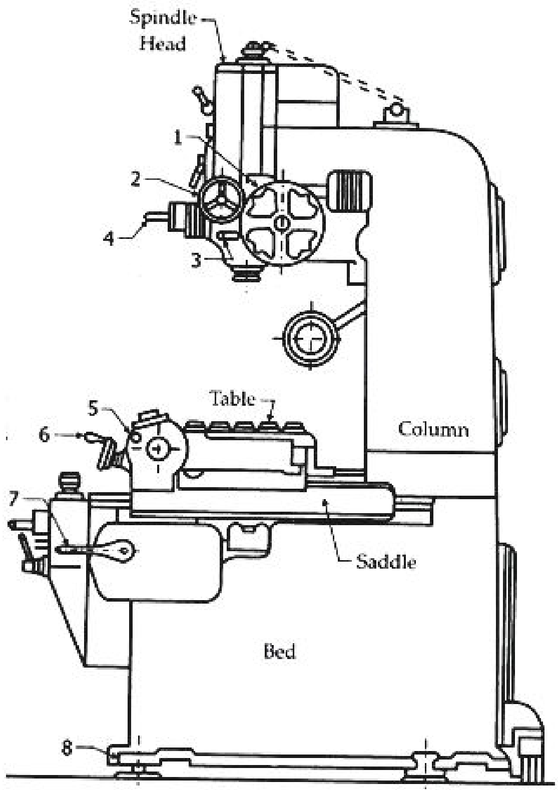
4. Electromagnetic System

This system consists of two Master Bars, attached one each to the underside of the table and the saddle. These bars carry a series of equi-spaced projections which are magnetized. The centre to centre distance between adjacent projections is constant and the total accumulated error for the total length of the bar is 0.005mm. Just below the table there is a Precision micrometer screw having a micrometer dial at its end. A movable slide is connected to this screw and a Magnetic

Head is fastened to the slide. This Head is also connected to a meter which gives a ‘zero’ reading when the magnetic centre of a projection is just in front of the Head. This is a very efficient system which enables a rapid traverse of table and saddle except at the end of the setting where a relatively slower movement is needed.

Detail Description of a Jig Borer

A High Quality Jig Boring Machine is illustrated in Figure. It carries an Electromagnetic System of Measurements. The diagram shows all its Main parts and Controls. It is basically designed for Drilling and Boring holes in Jigs, Fixtures, Templates, Gauges, Dies and other components of small and medium sizes, where a very accurate location of holes is needed. It can also be used for doing light milling work. The machine is also equipped with the plain rotary as well as inclined rotary tables, in addition to the rectangular table, so that the holes can be drilled and bored along the circumference of the work and also at an inclination. It carries a guaranteed accuracy of centre to centre distance of 0.006mm. This model of the machine conforms to the following main specification:



This machine consists of the following main parts:

1. ***Bed***: It is the main supporting member of the machine. It is made of cast iron and is highly rigid because of its box shaped construction having stiffening ribs. The column is mounted on it and at its top it carries guide ways for the saddle. Electrical for spindle drive and table feed drive are housed in it.
2. ***Column***: It is hollow vertical cast iron structure carrying vertical guide ways at its front for the vertical hand traverse of the spindle head. Counterweights for balancing the spindle head are housed inside it. It also carries the counterweight for balancing the spindle with the quill, clamping device for spindle head and the belt drive for spindle.
3. ***Spindle Head:*** It is mounted in front of the column. A Rack and Pinion mechanism, operated by a Hand wheel is used to adjust its position vertically. It carries the Quill, drive gear box and Feed gear box for the spindle. An indicator device is provided on it to measure the boring depth

correctly. A separate dial is provided at its front to set the length of spindle travel. The feed gear box provides 6 spindle feeds a stop disengages a clutch at the end of previously set travel to disengage the spindle feed automatically.

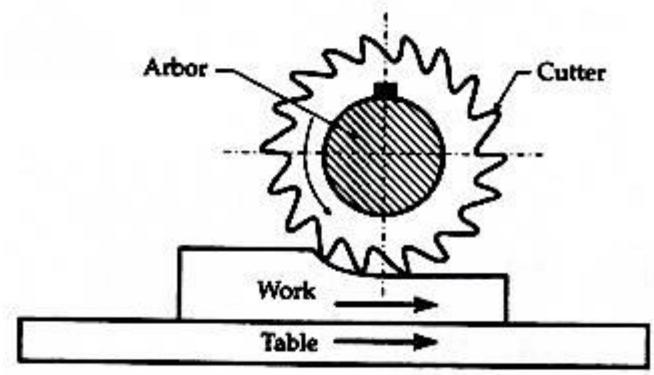
4. Table and Saddle: The table and Saddle are given longitudinal and transverse motions respectively by a separate Electric motor inside the bed. They also carry the Clamping and Measurements reading mechanisms. Rapid transverse of table and saddle is affected by a clutch operated by an Electromagnet. Verniers are provided for setting the table by hand. The plain and inclined Rotary tables are provided in addition to the Rectangular table for boring holes along the circumference of a job and at desired inclination respectively.

5. Pick up Device: An Electro-magnetic system is used for accurate setting of longitudinal and cross coordinates automatically and for automatic stopping of them as they reach nearer the previously set traverses. Pick up for longitudinal coordinate is mounted on the table and that for the cross coordinate on the saddle. The pickup device consists of a nut of 5mm pitch threads, a Coil to create an electric field and a screw of 5mm pitch threads. The coil moves along the screw with the nut and the indicator (or meter) shows the exact position of the table or saddle for each 5mm travel. Automatic switching off of electric current just before reaching the end of preset travel is accomplished by means of an adjustable stop. The remaining setting is done by hand. Coordinates can be set with accuracy up to 0.001mm three dials are provided for reading the setting of the coordinates, one giving the whole numbers of millimetres, second reads up to 0.01mm and the third reads up to 0.001mm.

Milling Machine

Working Principle in Milling

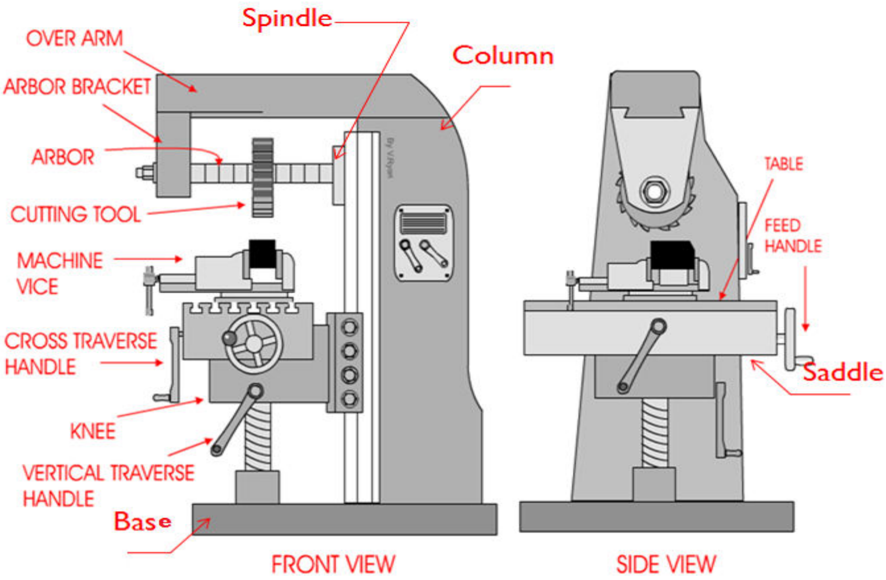
- The working principle, employed in the metal removing operation on a milling machine, is that the work is rigidly clamped on the table of the machine, or held between centres, and revolving multi-teeth cutter mounted either on a spindle or an Arbor.



- The cutter revolves at a fairly high speed and the work fed slowly past the cutter, as shown in Figure.
- The work can be fed in a vertical, longitudinal or cross direction.
- As the work advances, the cutter-teeth remove the metal from the work surface to produce the desired shape.

Principal Parts of a Milling Machine

Main parts of all the milling machines are similar, although the movements of the moving parts differ in them. All these machines essentially consists of the following main parts (See Figure :



Base

- It is a heavy Casting provided at the bottom of the machine.
- It is accurately machined on both the top and bottom surfaces.
- It actually acts as local bearing member for all other parts of the machine.
- Column of the machine is secured to it.
- Also, it carries the screw jack which supports and moves the Knee.
- In addition to this, it also serves as a reservoir for the coolant.

Column

- It is a very prominent part of a milling machine and is produced with enough care.
- To this, are fitted all the various parts and centrals.
- On the front face of the column are made the vertical parallel ways in which the knee slides up and down.
- At its rear side, it carries the enclosed meter drive.
- Top of the column carries dovetail horizontal ways for the over arm.

Knee

- It is a rigid casting, which is capable of sliding up and down along the vertical ways on the front face of the column.
- This enables the adjustment of the table height.
- The adjustment is provided by operating the Elevating jack, provided below the knee, by means of hand wheel or application of power feed.
- Machined horizontal ways are provided on the top surface of the knee for the cross traverse of the saddle, and hence the table.
- For efficient operation of the machine, rigidity of the knee and accuracy of its ways play an important role.
- On the front face of the knee two bolts are usually provided for securing the braces to it to ensure greater rigidity under heavy loads.

Saddle

- It is the intermediate part between the knee and the table and acts as a support for the latter.
- It can be adjusted crosswise, along the ways provided on the top of the knee, to provide cross feed to the table.

- At its top, it carries horizontal ways,. Along which moves the table during the longitudinal traverse.

Table

- It acts as a support for the work. The latter is mounted on it either directly or held in the Dividing head.
- It is made of cast iron, with its top surface accurately machine. Its top carries longitudinal T-slots to accommodate the clamping bolts for fixing the work or securing the fixtures.
- Also, the cutting fluid, after it is used, drains back to the reservoir through these slots and then the pipe fitted for this purpose.
- Longitudinal feed is provided to it by means of a hand wheel fitted on one side of the feed screw.
- Sometimes the hand wheels are provided on both sides or alternatively a detachable handle is provided, which can be engaged on either side.
- Cross feed is provided by moving the saddle and vertical feed by raising or lowering the knee. Both hand feed and power feed can be employed for all these movements.
- When power feeds are employed the Adjustable stops should be used to trip out the same at the correct moment.
- In addition to the above feeds, most of the modern milling machines carry mechanism to provide rapid traverse in all the three directions to affect saving in time.
- In Universal milling machines the table is made to have a graduated circular base resting on the saddle.
- Such a table can be swivelled in a horizontal plane around the centre of its base and the graduations on the latter help in adjusting the required swivel.

Overarm:

- It is the heavy support provided on the top of both plain and universal milling machines.
- It can slide horizontally, along the ways provided on the top of the column, and adjusted to a desired position in order to provide support to the projecting arbour by accommodating its free end in the Yoke.
- If further support is needed, to have additional rigidity, braces can be employed to connect the Overarm and the Knee.
- Such a requirement is always there when many cutters are employed simultaneously.

Specification of a Milling Machine

The following are the specifications of a column and knee type milling machine:

1. Width and length of the table.
2. Maximum distance the knee can travel.
3. Maximum longitudinal movement and cross feed of the table.
4. Number of spindle speeds.
5. Power of the main drive motor.

Classification of Milling Machines

A large variety of different types of milling machines is available and the broad classification of these machines can be done as follows:

Column and Knee Type Milling Machines

These machines are all General purpose machines and have a Single Spindle only. They derive their name 'Column and Knee' type from the fact that the work table is supported on a knee like casing, which can slide in vertical direction along a Vertical Column. These machines, depending upon the spindle position and table movements, are further classified as follows:

(a) Hand milling machine,

(b) Plain or Horizontal milling machine,

(c) Vertical Milling machine,

(d) Universal Milling machine, and

(e) Omniversal Milling machine.

Fixed Bed Type or Manufacturing Type Milling Machines

These machines, in comparison to be column and Knee type, are more sturdy and rigid, heavier in weight and larger in size. They are not suitable for tool room work. Most of these machines are either automatic or semi-automatic in operation. They may carry a single or Multiple Spindles. The common operations performed on these machines are Slot Cutting, Grooving, Gang Milling and Facing. Also, they facilitate machining of many jobs together, called Multi-piece Milling. Their further Classification is as follows:

(a) Plain Type (having Single Horizontal Spindle).

(b) Duplex Head (having Double Horizontal Spindle)

(c) Triplex Head (having two Horizontal and one Vertical Spindle)

(d) Rise and Fall type (for Profile Milling)

Planer Type Milling Machines

They are used for heavy work. Upto a maximum of Four Tool heads can be mounted over it, which can be adjusted vertically and transverse directions. It has a robust and massive construction like a Planer. Its detailed description will follow in latter articles.

Production Milling Machines

They are also Manufacturing Machines but differ from the above described machines in that they do not have a fixed bed. They include the following machines:

(a) Rotary Table or Continuous Type

(b) Drum Type, and

(c) Racer Controlled.

Special Purpose Milling Machines

These machines are designed to perform a specific type of Operation only. They include the following machines:

(a) Thread Milling Machine,

(b) Profile Milling Machine,

(c) Gear Milling or Gear Hobbing Machine,

(d) Cam Milling Machine,

(e) Planetary Type Milling Machine

(f) Double end Milling Machine

(g) Skin Milling Machine, and

(h) Spar Milling Machine.

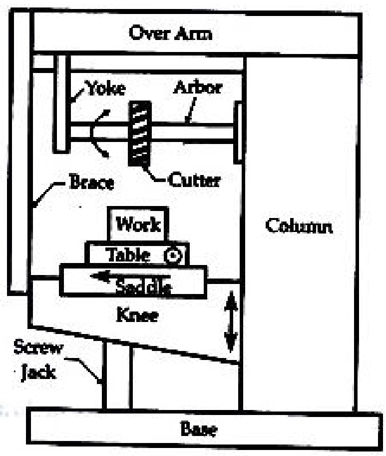
Description of Milling Machines:

Column and Knee Type Milling Machines

Hand Milling Machine

- It is the simplest of all the Milling Machines and smallest in size.
- All the operations, except the rotation of arbour, are performed by hand.
- The table, carrying the work over it, is moved by hand to feed the work.
- This machine is especially useful in producing small components like Hexagonal or Square Heads on Bolts, Cutting slots on Screw heads, Cutting Key ways, etc.

Plain or Horizontal Milling Machine

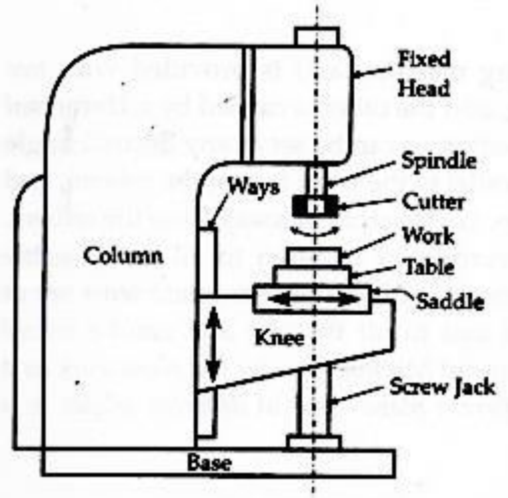


- Its principal parts are shown by means of a block diagram in Figure.
- The vertical column serves as a Housing for Electricals, the main drive, spindle bearings, etc.
- The knee acts as a support for the Saddle, Worktable and other accessories like indexing Head, etc.
- Over arm provides support for the Yoke which in turn, supports the free end of the Arbor.
- The arbor carrying the cutter rotates about a horizontal axis.
- The table can be given straight motions in three directions; longitudinal, cross and vertical (up and down) but cannot be swivelled.
- For giving vertical movement to the table the knee itself together with the whole unit above it, slides up and down along the ways provided in front of the column.
- For giving cross movement to the table, the saddle is moved towards or away from the column along with the whole unit above it.
- A Brace is employed to provide additional support and rigidity to the arbour when a long arbour is used. Both hand and power feeds can be employed for the work.

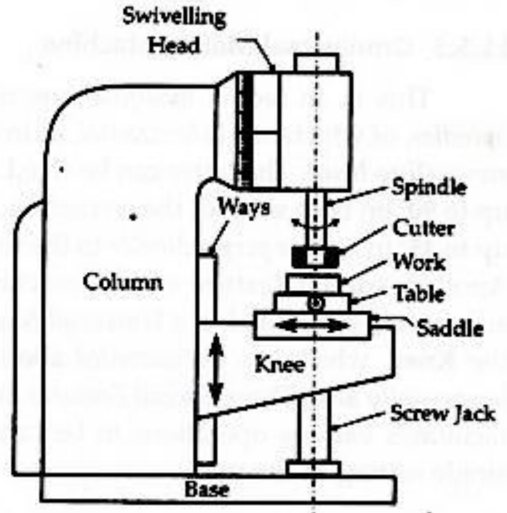
Vertical Milling Machine

- It derives its name from the vertical position of the spindle.
- This machine is available in both types; the Fixed bed type as well as Column and Knee type.
- Principal parts of the latter type are illustrated by means of block diagrams shown below.
- It carries a Vertical Column on a heavy base.
- The overarm in this machine is made integral with the column and carries a housing at its front.

- This housing, called head can be Fixed type (see figure) or Swivelling type (see figure).



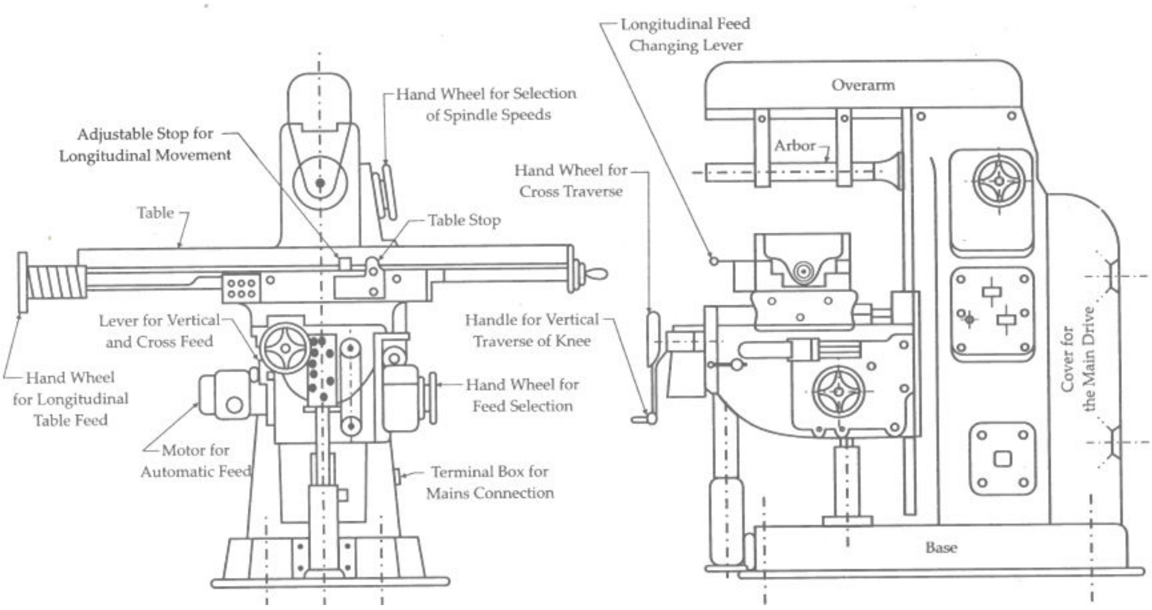
Vertical Milling Machine
with Fixed Head.



Vertical Milling Machine
with Swivelling Head.

- In fixed type, the spindle always remains vertical and can be adjusted up and down.
- In swivelling type, the Head can be swivelled to any desired angle to machine the inclined surfaces.
- The Knee carries an enclosed Screw jack, by means of which it is moved up and down along the parallel vertical Guide ways provided on the front side of the Column.
- The Saddle is mounted on the knee and can be moved, along the horizontal guide ways provided on the Knee, towards or away from the column.
- This enables the Table to move in cross direction.
- The Table is mounted on guide ways, provided on the saddle; which are in direction normal to the direction of the guide ways on the Knee.
- By means of a Lead screw, provided under the table, the table can be moved in the longitudinal direction.
- Thus, the work gets up and down movement by the knee, cross movement by saddle and longitudinal movement by the table.
- Power feeds can be employed to both the saddle and the table. Mostly Face Milling Cutters and Shell-end type Cutters are used on these machines.

Universal Milling Machine



- Detailed parts and various controls of a universal milling machine are shown in Figure.
- It is the most versatile of all the milling machines, and after lathe it is the most useful machine tool as it is capable of performing most of the machining operations.
- With its application, the use of a large number of other Machine tools can be avoided.
- It differs from the Plain milling machine only in that the table can be given one more additional movement.
- Its table can be swivelled on the saddle in a horizontal plane. For this, Circular guideways are provided on the saddle along which it can be swivelled.
- A graduated circular base is incorporated under the table with a datum mark on the saddle, to read directly the angle through which the table has been swivelled.
- This special feature enables the work to be set at an angle with the cutter for milling helical and spiral flutes and grooves.
- Its overarm can be pushed back or removed and a vertical milling head can be fitted in place of the arbour to use it as a vertical milling machine.

***Comparison between plain and universal milling*:**

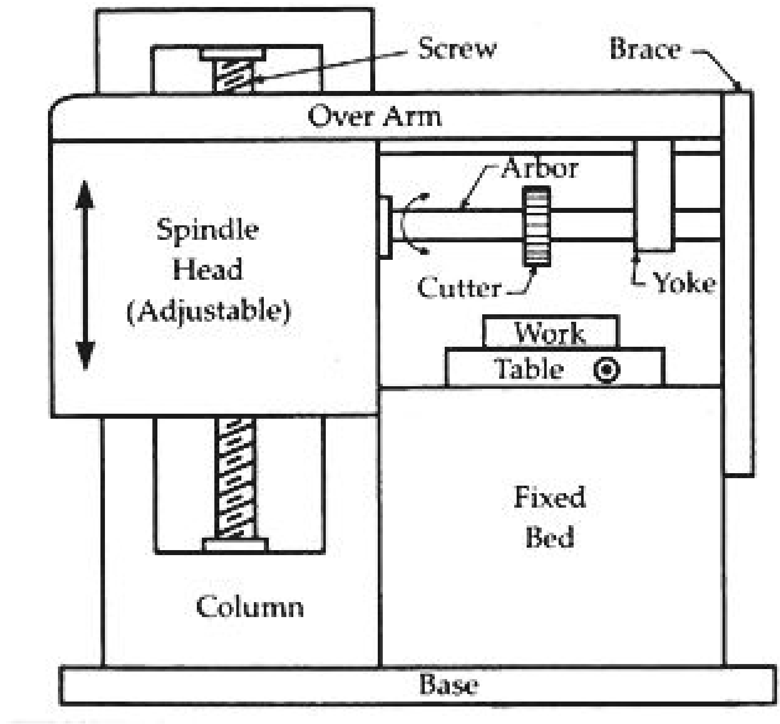
- The plain milling machine is provided with three table movements: longitudinal, cross and vertical, whereas a universal milling machine has a fourth movement of the table in addition to the above three. The table can be swivelled horizontally and can be fed at an angle to the milling machine spindle.
- The universal milling machine is provided with auxiliaries such as dividing head equipment, vertical milling attachment, rotary table, etc. These extras and the special design of the machine itself make it possible to produce spur, spiral bevel gears, twist drills, reamers, milling cutters and all types of milling, drilling and shaping operations.
- The plain milling machine is more rigid and heavier in construction than a universal machine of the same size, and is intended for heavier milling operations. The plain type is particularly adapted for manufacturing operations, whereas the universal machine is intended more for tool room work and for special machining operations.

Omniversal Milling Machine

- In this machine, the table besides having all the movements of a universal milling machine, can be tilted in a vertical plane by providing a swivel arrangement at the knee.
- Also the entire knee assembly is mounted in such a way that it may be fed in a longitudinal direction horizontally.
- The additional swivelling arrangement of the table enables it to machine taper spiral grooves in reamers, bevel gears, etc. It is essentially a tool room and experimental shop machine.

Fixed Bed Type or Manufacturing Type Milling Machine

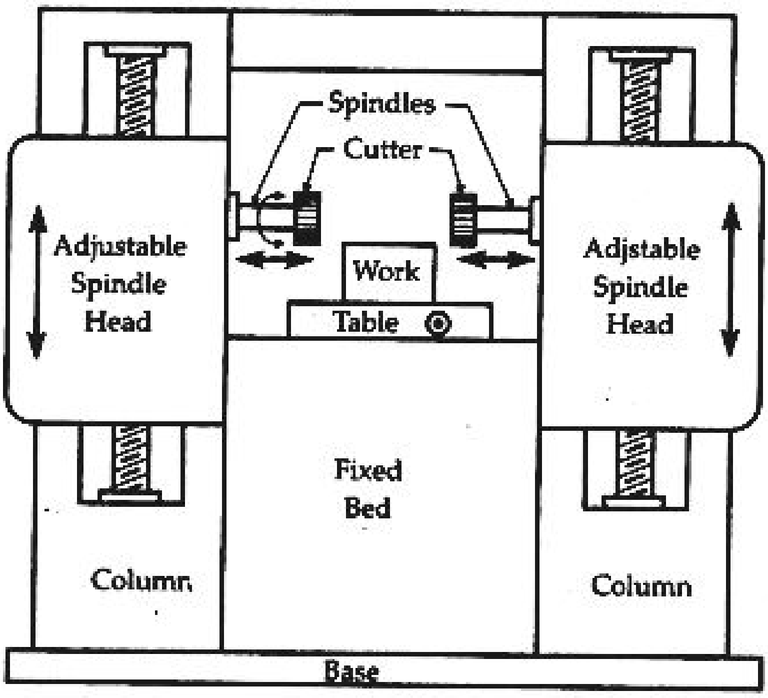
Fixed Bed Type Plain Milling Machine



v

- Main parts of this type of machine are shown by means of a block diagram in Figure.
- It differs from the column and Knee type Plain Milling Machine in that the table is mounted on a fixed bed instead of the saddle and Knee and has a longitudinal travel only.
- It can neither move up and down nor crosswise.
- A rigid vertical column carries parallel vertical ways on which is mounted the adjustable spindle head or spindle carrier.
- This spindle head carries the spindle to which the arbour can be fitted to carry the cutter.
- The carrier can be moved up and down along the column ways to adjust the tool to the work.

Duplex-Head Fixed Bed Type Milling Machine



- ➢ It is another useful form of Fixed bed type Milling machine.
- ➢ In construction, it is similar to the fixed bed type plain milling machine, except that it carries two vertical columns instead of one.
- ➢ The columns are one each on both sides of the fixed bed, as shown in Figure.
- ➢ Both the columns carry parallel vertical ways, on which are mounted the two adjustable spindle heads or spindle carriers, as shown.
- ➢ Both threes carriers carry a horizontal spindle each on which cutters can be mounted.
- ➢ The spindle carriers can be adjusted vertically up and down to adjust the cutters to the work.
- ➢ The table has a longitudinal movement only and cannot be moved in any other direction.
- ➢ This machine enables machining of two surfaces simultaneously.

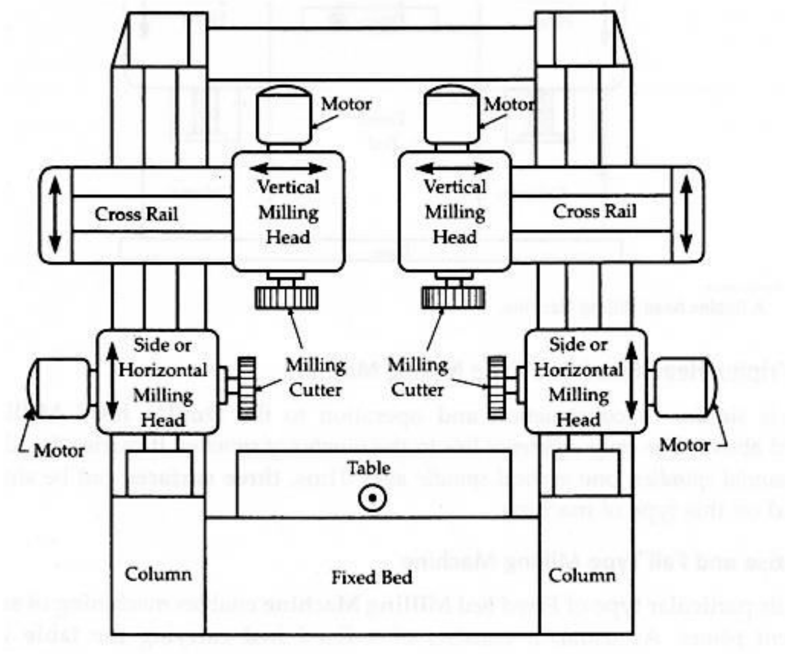
Triplex-Head Fixed Bed Type Milling Machine

- ➢ It is similar in construction and operation to the duplex head milling machine.
- ➢ The only difference lies in the number of spindles.
- ➢ It carries, in addition to the two horizontal spindles, one vertical spindle also.
- ➢ Thus, three surfaces can be simultaneously machined on this type of machine.

Rise and Fall Type Milling Machine

- ➢ This particular type of Fixed bed Milling Machine enables machining of surfaces lying in different planes.
- ➢ As usual, it consists of a fixed bed carrying the table which has a longitudinal movement only.
- ➢ The spindle carrier carries a horizontal spindle.
- ➢ An automatic cycle, operated either hydraulically or electrically, synchronises the vertical movement of the spindle carrier and longitudinal movement of the table, such that it enables machining of surfaces which lie in different places, blind or hidden portions and curved profiles, etc.
- ➢ In all other respects it resembles the Fixed bed type Plain Milling Machine.

Planer Type Milling Machine



- It derives its name from its appearance, construction and up to a certain extent, the working also.
- It is very much similar to a Double Housing Planning machine, the only difference being in the tool heads.
- In this case, the spindle carriers are mounted, in place of the planer tool posts, which are operated by individual motors.
- This type of milling machine represents the largest size of fixed bed type Milling Machines.
- Because of their planer type construction, they are frequently known as Plano-mills.
- A typical type of Plano-mill is shown by a block diagram in Figure.
- It consists of a fixed bed, carrying the table, which has a longitudinal movement only.
- Two vertical columns, one each on the two sides of the bed, carry a Milling head each.
- A Bridge or Cross-rail is fitted, as shown across the columns or housings, as they are better known in this case.
- This cross-rail can be raised or lowered to suit the height of the work.
- Two vertical Milling heads are fitted on the cross-rail, which can travel along it.
- The two side milling heads can move up and down along the respective housing.
- All the four cutters can be operated simultaneously to machine four surfaces on the work at a time.
- The main difference between a Planer and this machine is in table movement. The table in this machine moves slow and provides feed only while that in a Planer moves faster and provides the cutting speed to the operation.

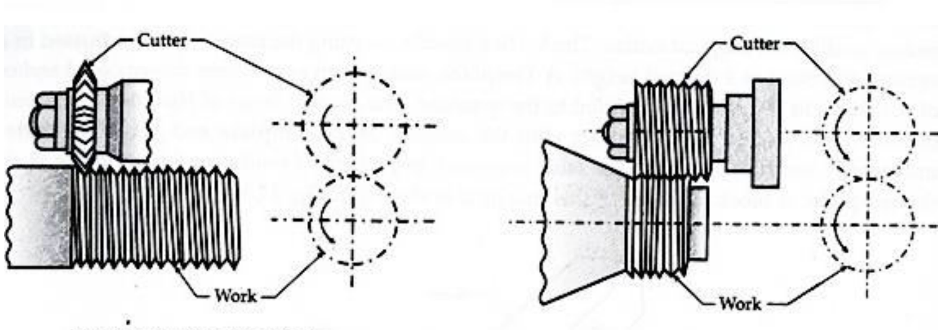
The work can be machined in four different ways, according to requirements, as follows:

- By moving the table, the cutters rotating in position.
- By keeping the table stationary and feeding the cutters by moving the milling heads.
- By moving the table and the Milling head simultaneously.
- By keeping the table stationary, moving the cross-rail downwards and the side cutters up and down.

- These Milling machines are constructed for very heavy-duty work where generally flat surfaces are to be machined.
- The Milling heads mounted on these machines can be of fixed type or swivelling type, the latter type facilitating machining of inclined surfaced also.
- Number of these heads depends upon the number of surfaces to be machined at a time.
- Sometimes a single horizontal arbour is mounted on these machines to carry several cutters for Gang milling.

Special Purpose Milling Machines

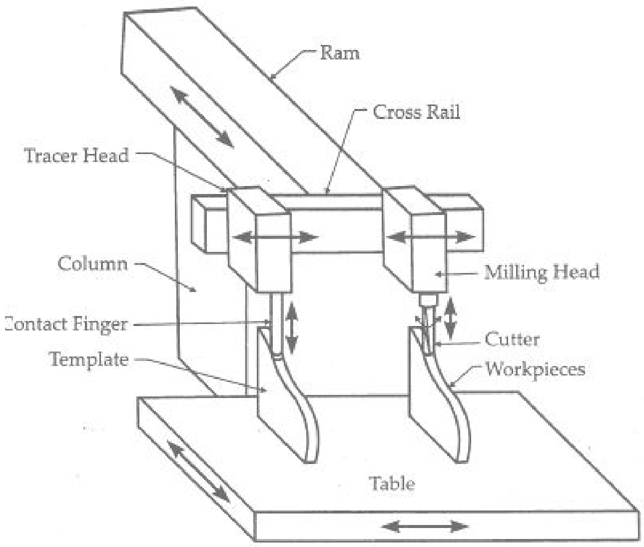
Thread Milling Machine



Thread milling by a Single Cutter. Thread milling by a Multi-teeth Cutter.

- The Thread Milling Machine is used to cut threads and worms, etc., by means of the milling cutters.
- This operation is known as thread milling and ensures greater accuracy and better finish than the other common methods of thread cutting e.g., on lathe or by taps and dies, etc.
- Two types of cutters are generally used in thread milling. One of these consists of a single row of teeth mounted on the periphery of a Cylinder (see figure) and the other consists of a number of such rows, spaced at a distance equal to pitch from one another, as shown in Figure.
- The single cutter shown in figure is generally used for cutting threads of coarse pitches and on long screwed parts, such as lead-screw and worms, etc.
- The other form, shown in figure is used for comparatively shorter lengths.

Profile Milling Machine



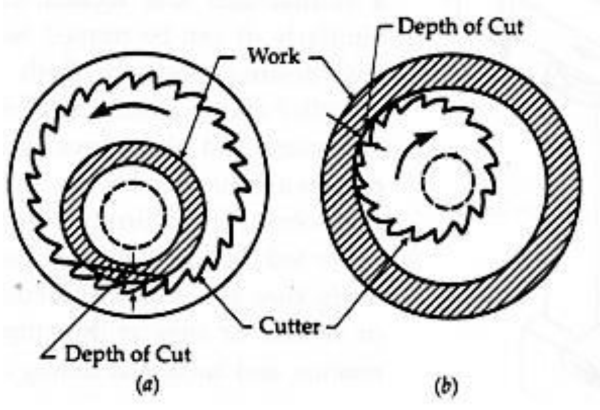
- This machine is made in both Vertical and Horizontal types, i.e., carrying vertical or horizontal spindle.
- Machining is done in two dimensions only. The machine may have one to four spindles, carrying the revolving cutters, as usual.
- The cutter movement is guided by the path of a tracer which travels along the outside surface of a template, thus acquiring the same path as the shape of this template.
- End-mill cutters are used on this machine. The tracer mechanism can be operated by hand or hydraulically.
- A device is usually incorporated which enables an automatic disengagement of the tracer mechanism from the operation when it loses contact with the surface of the template. (see figure).

Gear Milling Machines

- Gears can be cut on all plain and Universal types of milling machines.
- This specific classification 'Gear milling' actually includes Gear hobbing machines which are regarded as milling machines for the reason that the hobbing tools or 'hobs' are in the shape of inserted teeth milling cutters and are fed while revolving exactly in the same manner as the milling cutters.

Planetary Milling Machine

- It derives its name from the Planetary (circular) path that its cutter or cutters adopt during the operation.
- These machines are available in both Horizontal and Vertical spindle types.
- A special feature of these machines is that, contrary to the normal method, the work is held stationary while the revolving cutters move in a circular path to machine the surface either separately or simultaneously, as desired.
- Special use of these machines is in machining heavy or delicate type of work, which cannot be rotated and fed against the cutter.
- The operation is also called Plana-milling.
- Another specific use of this type of machine is in simultaneously milling external and internal threads of different pitches or milling threads in different holes, whose centres lie on a circle, in a single setting without disturbing the work piece.
- This operation is usually termed as Plana-threading.



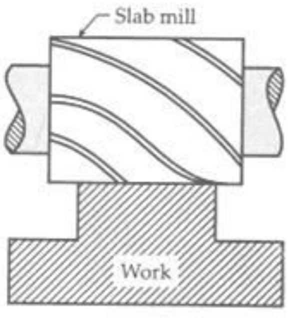
- The principle of planetary milling is illustrated in figure (a) and (b).
- In both the diagrams the cutters are shown in the starting position of the cut.
- The small dotted circles indicate the paths of the centres of the respective cutters.

Milling Operations

A large variety of components are machined on a Milling Machine involving various types of operations. These operations are broadly classified as follows:

- Plain or Slab Milling
- Angular Milling
- Straddle Milling
- Face Milling
- Form Milling
- Gang Milling

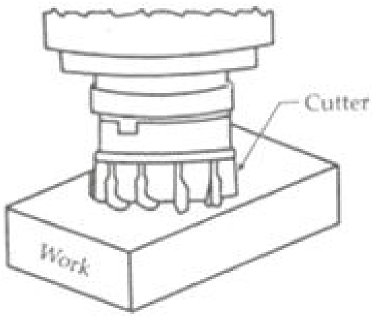
Plain or Slab Milling



Plain or Slab Milling.

- It is the Process which is employed for machining a flat surface, parallel to the axis of the cutter, by using Plain or slab milling cutter, as shown in figure.
- When a very wide surface is to be machined, it is advisable to use the interlocking teeth plain milling cutters instead of simple slab mills.
- In using them, they should be so arranged that the axial forces are directed towards each other so as to force the cutters closer as the operation proceeds.

Face Milling

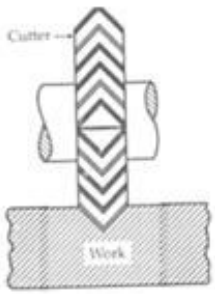


- This milling process is employed for machining a flat surface which is at right angles to the axis of the rotating cutter. The cutter used in this operation is the Face Milling Cutter (see figure).

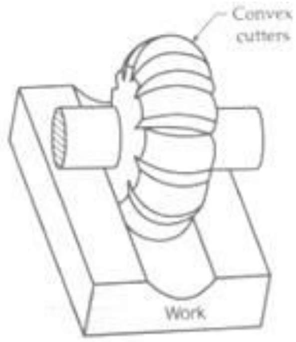
Angular Milling

- It is the milling process which is used for machining a flat surface at an angle, other than a right angle to the axis of the revolving cutter.

➢ The cutter used may be a Single or Double Angle Cutter, depending upon whether a single surface is to be machined or two mutually inclined surfaces simultaneously (see figure).



Angular Milling.



Form Milling.

Form Milling

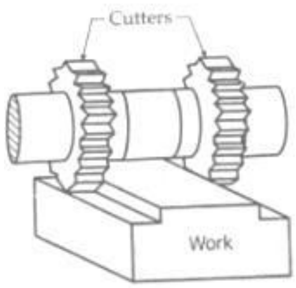
This milling process is employed for machining those surfaces which are of irregular shapes. The cutter used, a Form Milling Cutter, will have the shape of its cutting teeth.

Straddle Milling

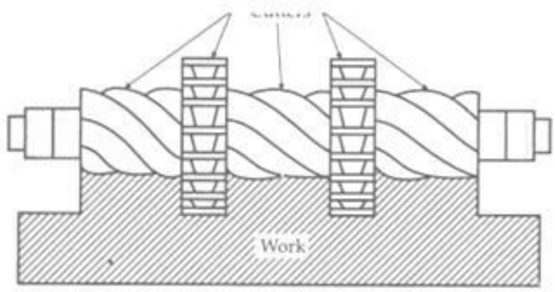
It is a milling operation in which a pair of Side Milling cutters is used for machining two parallel vertical surfaces of a work-piece simultaneously. (See Figure)

Gang Milling

It is the name given to a milling operation which involves the use of a combination of more than two cutters, mounted on a common arbor, for milling a number of flat horizontal and vertical surfaces of a work-piece simultaneously. This combination may consist of only Side Milling Cutters or of Plain and Side Milling Cutters both. Figure shows the Gang Milling Operation.



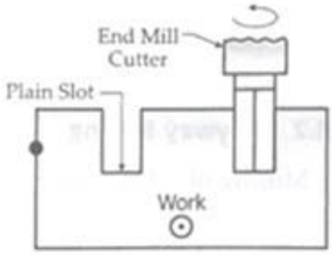
Straddle Milling.



Gang Milling.

Apart from this, a number of other operations are named either after the name of the cutter used for them or some other factors like the shape or use of the surface produced. These operations are, however, the variations of these standard operations only and may involve one or a combination of more than one of the above operations.

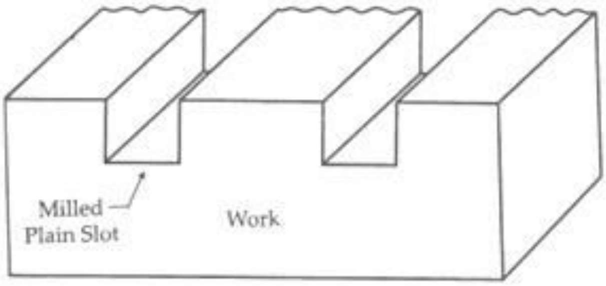
Slot and Groove Milling

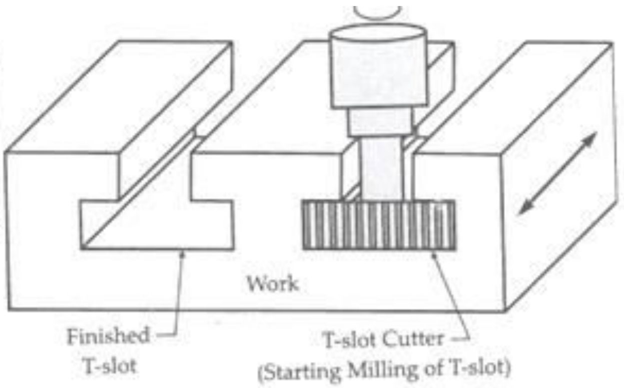


Milling a Plain Slot by means of an End Mill Cutter.

- Slot Milling is the operation of producing slots in solid workpiece on a milling machine.
- These slots can be of varied shapes, such as plain slots, T-slots, dovetail slots, etc.
- Similarly, Groove Milling is the operation of producing Grooves, V-grooves, etc.
- The Cutter to be used is chosen according to the shape of the groove or slot to be produced Milling of a V-groove, using a Double Angle Cutter, is shown in angular milling.
- The same result can be obtained with two single Angle Cutters of opposite angles, used one after the other.
- Similarly, Plain Grooves or Slots can be milled by means of a Plain Milling Cutter, an End mill, a Slitting saw or a Side milling cutter (see figure).

<u>*Milling of T-slot and Dovetail slot*</u> is carried out in two or three stages. In the first stage an open slot, from one end of the solid workpiece to its other end, is first with the help of a suitable cutter, say a plain milling cutter or an End Mill. Then the slot is milled to the required shape by using a special cutter-a T-slot Cutter for T-slot and a Dovetail Milling cutter for Dovetails slots. The operation of finish milling a T-slot is shown in figure.

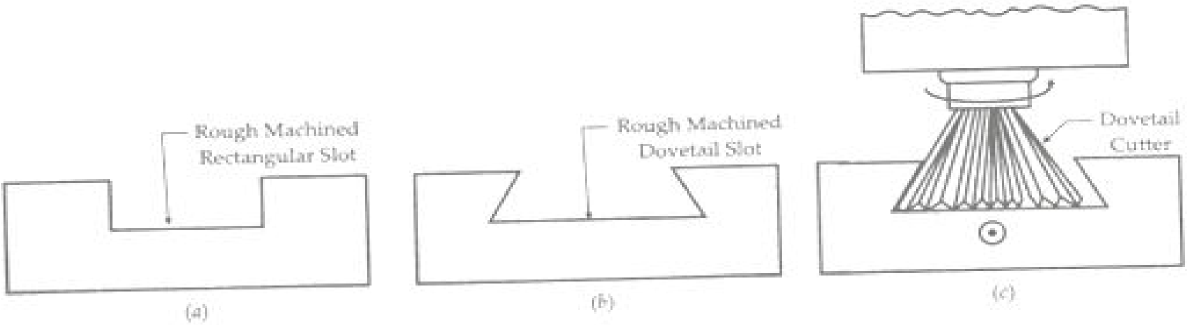




(a) Work having Milled Plain Slots.

(b) Milling T-slots with T-slot Milling Cutter

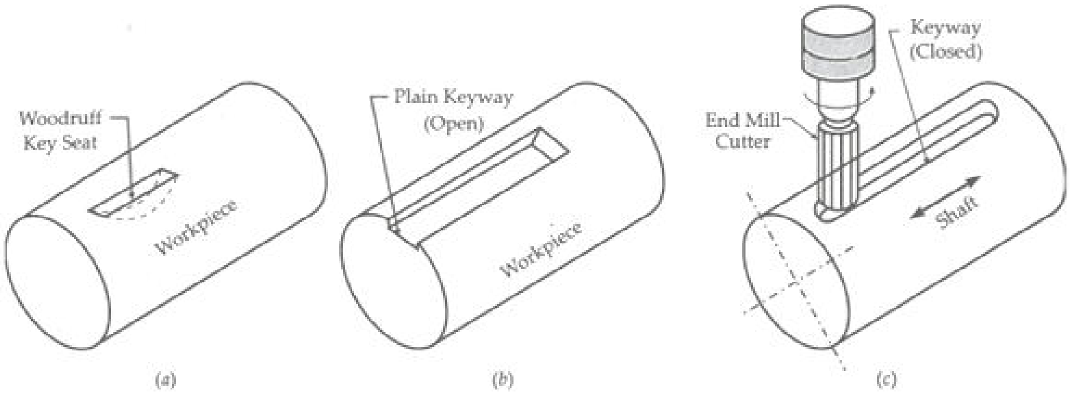
Production of Dovetail slot in three stages is shown in Figures. Figure (a) is shown a rectangular slot produced through rough machining by means of a Plain Milling Cutter. The required angles of the dovetail are then rough machined by means of a Form Angle Cutter and a rough machined Dovetail slot obtained, as shown at (b). The slot is finally finished by machining the base and sides of the slot with the help of a Dovetail Milling Cutter as shown in figure c.



Milling a Dovetail Slot. (a) Rough machined rectangular slot (b) Rough machined Dovetail Slot (c) Finish machining the Dovetail Slot with the help of a Dovetail Milling Cutter.

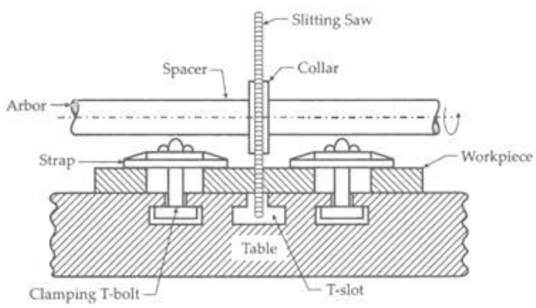
Keyway Milling

- Milling of a Keyway is a commonly performed operation on a milling machine in which a Groove is milled, usually on shafts and spindles.
- This groove is known as Key Seat. The groove can be open or closed, depending upon the type of key to be used and the position in which it is to be used.
- Figure shows the three common forms of key seats. In Figure (a) is shown a Woodruff Key Seat milled with a Woodruff Key seat Cutter. It is a closed groove with a rounded bottom.
- In Figure (b) is shown a Plain Key seat milled with a Single Plain or Side milling cutter. It is an open groove.
- At Figure (c) is shown the operation of milling a key seat for a Sunk key with the help of an End mill Cutter. It is a closed groove with rounded ends. This type of key seat can be produced anywhere along the length of the workpiece. Same is the case with Woodruff key seat.



Keyway Milling. (a) A Woodruff Key Seat (b) A Plain (open) Key Seat (c) A Sunk (closed) Key Seat.

Slitting or Saw Milling



A Slitting Saw being used for Parting Off operation.

A Slitting Saw or Slitting Cutter is used for many purposes on a milling machine, such as Parting off a solid workpiece into two, cutting of narrow slots and grooves, etc.

An important factor in any slitting operation is the rigidity of the workpiece.

If the component has such a cross-section that no deflection is likely to be produced during cutting, it can be safely gripped in a vice such that the portion to be cut-off extends beyond the jaws of the vice.

In other cases, the work piece may be clamped directly on the machine table using suitable job holding devices.

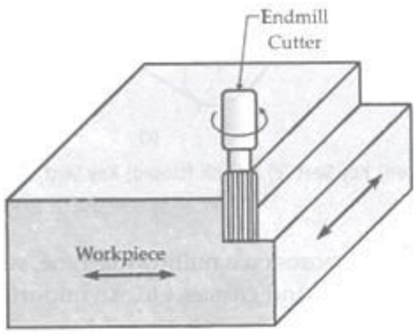
An important precaution in this case is to keep the line of cutting in the centre of a T-slot and running along its length.

This will allow the slitting saw to project safely into the free space in the slot to prevent its teeth from being damaged. A Parting off operation, being performed by means of a Slitting Saw, is shown in figure.

Side Milling

In this operation, a Side Milling Cutter is used to machine a flat vertical surface on a side of the workpiece. When two parallel vertical flat surfaces are required to be machined, the usual time saving practice is to use a pair of two Side Milling Cutters to Machine both the surfaces simultaneously. The space between the two cutters can be easily adjusted as per requirement by using the Spacers. This operation is then known as 'Straddle Milling'.

End Milling



Producing a Single Flat Surface by using an End Mill Cutter.

- In this operation and End Mill Cutter is used to machine and produce a flat surface or a pair of parallel flat surfaces.
- When the operation is performed at the end of a workpiece, as shown in figure, a single flat surface is produced.
- If however, the operation is performed in such a way that cutting of metal takes place on both sides of the cutter; two parallel flat surfaces are produced.
- The surfaces produced may be horizontal, vertical or inclined with respect to the top of the machine table.
- For producing a horizontal surface, the axis of rotation of the Cutter has to be horizontal, for vertical surface it remains vertical and for inclined surface it is to be set at proper inclination with the table top.

Profile Milling

It is the operation in which the Profile of a Template or the shape of the cavity of a Master-die is duplicated on the work surface. The movement of the cutter is guided by a Tracer control unit which carries a contact finger. This Finger runs in contact with the outline to be duplicated and the Tracer mechanism guides the tool movement accordingly.

Gear Milling

This operation, often referred to a Gear Cutting, involves cutting of different types of gears on a milling machine. For this, either an End-mill Cutter or a Form relieved Cutter is used, which carries the profile on its cutting teeth corresponding to the required profile of the gap between gear teeth. For dividing the periphery of the gear blank into required number of equi-spaced parts an Indexing Mechanism or Dividing Head is used.

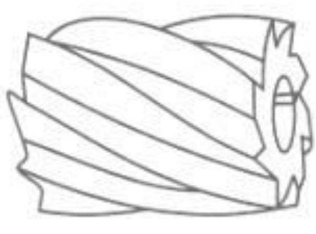
Milling Cutters

- The Milling Cutters may have either Straight teeth, i.e., parallel to the axis of rotation or in Helical shape.
- The Helix angle may be right hand or left hand and this will decide the direction of rotation of the cutter for performing the cutting operation.
- Further, a Milling Cutter may be made of single piece of steel or having the cutting portion welded to a tough shank or having removable Cutting teeth (bits) inserted in a solid body.
- The broad classification of milling cutters is according to the shape of teeth they carry, such as Plain, Inserted, Formed or Saw teeth, etc.
- Under this classification are covered a large number of milling cutters. Common types of Milling Cutters are the following:

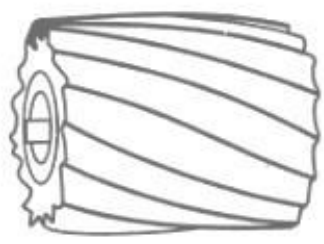
1. Plain Milling Cutters	2. End Milling Cutters
3. Metal Slitting Cutters (Slitting Saws)	4. Formed Milling Cutters
5. T-Slot Milling Cutters	6. Side Milling Cutters
7. Face Milling Cutters	8. Angle Milling Cutters
9. Woodruff- Milling Cutters	10. Fly Cutters

Plain Milling Cutters

Plain Milling Cutter.



Coarse Helical teeth Slab Mill.

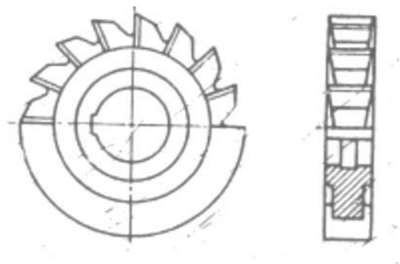


Fine Helical teeth Slab Mill.

- These Milling Cutters may have the cutting teeth on their periphery.
- The teeth may be either straight, i.e., parallel to the axis, or Helical.
- Their end faces are either ground square with the axis or slightly concave to reduce friction.
- Thus, no Cutting Action is provided by the side faces.

- These cutters are employed for milling flat surfaces parallel to the axis of rotation.
- These cutters include the light duty plain milling cutter or key way cutter (see figure) and the Helical or Slab Milling Cutters (see figure).
- The former type is available up to 20 mm in width and carries straight teeth. It is usually employed for key way and Slot cutting.
- The latter type, i.e., Slab Milling Cutters are enough long and carry helical teeth.
- These cutters are made to have either Fine pitch or Coarse pitch.
- Fine pitch teeth cutters are used for light work and finishing work.
- The Coarse pitch teeth cutters are called Heavy Duty Slab Milling Cutters.
- They carry less number of teeth, having a teeth, having a steep helix angle.
- They are commonly used where very heavy cuts are to the employed, since they are capable of removing more material with less power consumption.

Side milling cutter



- The side milling cutters have teeth on its periphery and also on one or both of its sides.
- The side milling cutters are intended for removed metals from the side of a work.
- The side milling cutters are available from 50 to 200 mm in diameter and the width of the cutter ranges from 5 to 32 mm.
- The different types of side milling cutters are described below:

The main types of Side Milling Cutters are the following:

1. *Plain Side Milling Cutters*: They are made to have cutting teeth on the periphery as well as on both sides, as shown in figure. They are normally used for cutting slots or in Face milling. They can also be used in pairs for straddle milling. These cutters are available in different widths ranging from 5 mm to 25 mm and diameters up to 200 mm.
2. *Half Side Milling Cutters*: These cutters have teeth on the periphery and on one side only. They can be used for Face milling. The teeth may be either Straight or helical. Also they can either Right hand or Left hand. Actual cutting operation is performed by the teeth provided on the periphery while the side teeth do the Finishing and Sizing work. A distinct feature of these cutters is that their teeth are longer than those of the Plain milling cutters. They are frequently used in pairs (one left hand and one right hand) form milling two parallel surfaces simultaneously; the operation being known as Straddle Milling.
3. *Staggered Teeth Side Milling Cutters*. These cutters carry alternate teeth on the periphery only. These alternate teeth are of opposite helix angle, staggered from side to side, just as the teeth of a wood saw, and cut alternately on one side and then on the other. They are commonly used for keyway cutting and slot cutting. They prove very efficient in milling Deep slots but narrow in width. A typical Teeth type of Staggered Tooth Side Milling Cutter is shown in figure.

Staggered teeth Side Milling Cutter.

Interlocking Side Milling Cutter.

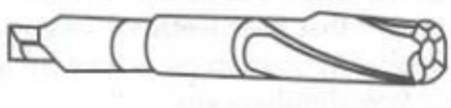
4. *Interlocking Side Milling Cutters*. These cutters are similar in design to the Side milling cutters but are used as a unit, consisting of two cutters joined tighter such that their teeth interlock, as shown in figure. They can be adjusted to acquire the required width by inserting shims or spacers between them. These shims or spacers are also used to make good the reduction in width of the cutters due to wear and frequent sharpening of the teeth. These cutters are used for milling relatively wider slots to exact width. Also, they find a wide use in Gang milling.

End Milling Cutters

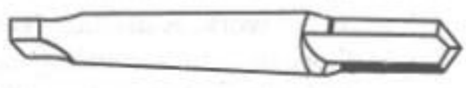
- These are solid Circular Cutters which are manufactured in two different varieties; those having the shank and the others which do not have the shank.
- They carry teeth on the periphery as well as on the end.
- These teeth may be Straight i.e., parallel to the axis of rotation, or Helical as in Slab milling cutters.
- Helical teeth may be Right hand or Left hand.
- End Milling Cutters are used for milling slots, keyways, grooves and irregular shaped surfaces.
- Shank type End mills may have either taper shank or straight shank and are available in a wide range of diameters from 3 mm to 50 mm.
- Shank type End mills are either mounted directly on the spindle, or held in Collets (straight shank type mills only) or in an adaptor.

The following are the main classifications of these End mills:

1. *Common Type*: These milling cutters carry multiple teeth on their periphery and also on the end. The teeth may be straight or helical; the former type is, however, available in small sizes only, say below 8 mm dia. A typical design of this type is shown in figure.



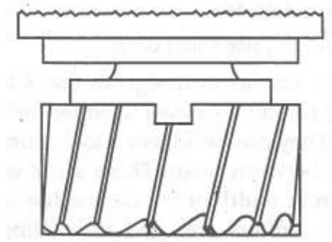
Common type End Milling Cutter.



Two-lipped Taper shank End Milling Cutter.

2. *Two-lipped End Mill*: These milling cutters are also known as Slotting Mills. These cutters have two straight or helical teeth on the periphery and the corresponding two teeth on the end, which meet at the end centre. The main advantage of these cutters is that they can be fed straight into the metal like a drill and then fed longitudinally to produce a groove of desired length and depth. Also, they can be used for taking heavy cuts in solid stock. These cutters may have either a Straight shank or a Taper Shank. The latter type is however, more commonly used (see figure).

3. *Shell End Milling Cutters*: These cutters are larger and heavier than most of the other types of End mills. They have teeth on the periphery and the end both. Generally they are made in over 50 mm size (diameter). The end face of these cutters is provided with a recess to receive a cap screw. They are held in stub arbor, shown in figure. Two slots are made across the back of the cutter, which engage the Collar keys of the arbor to get the drive. Generally helical teeth are provided on these cutters. These teeth may be Right hand or Left hand. These cutters are employed for heavy duty work. Milling of flat surfaces, using the end or face, and cutting slots, etc. are the common operations performed by them. The former operation is called Facing. A Shell End Milling Cutter is shown in figure.

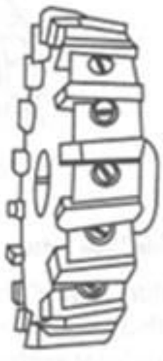


Shell-End Milling Cutter.

Face Milling Cutters

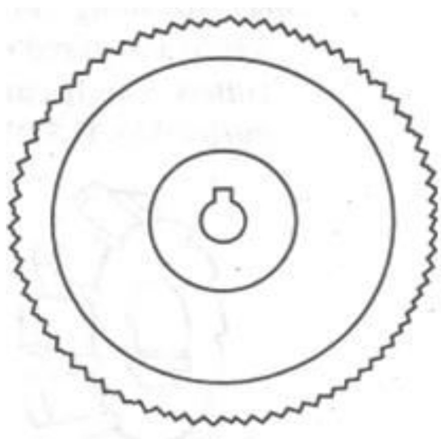
- These cutters are made in two common forms.
- The smaller type almost resembles a shell end milling cutter and is known as Shell-type Face Milling cutter (see figure). It carries teeth on the periphery as well as the end face. Maximum cutting is done by the teeth on the periphery and those on the face perform a type of finishing operation.
- The larger type of cutter, called the Built-up Face Milling Cutter, consists of a steel Body, along the periphery of which are inserted the cutting teeth (see figure). The former type is used for small work whereas the later for larger surfaces. The Shell-type Cutter is usually held in a stub arbor and the larger type can be mounted directly on the spindle nose.

Shell type Face Milling Cutter.



Build-up type Face Milling Cutter.

Metal Slitting Cutter



Metal Slitting Saw.

- These cutters are also frequently called Metal Slitting Saws.
- They are used for cutting thin slots or for parting off.

They are commonly manufactured in the following two varieties:

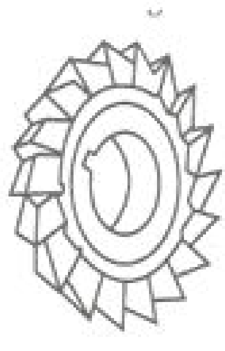
1. ***Plain Slitting Saws***: They are Plain milling cutters which are very thin as compared to other types of milling cutters. Their teeth are provided with some side relief in order to prevent rubbing. They are made in different widths, ranging between approximately 1 mm and 5 mm. A Plain Slitting Saw is shown in figure.
2. ***Staggered Teeth Milling Cutter (Saw):*** These saws are used for comparatively heavier work. They have their teeth staggered alternately and have side teeth also, similar to the Staggered Teeth Side Milling Cutter. These saws are generally made in different widths, ranging between 4 mm and 10 mm.

Angle Milling Cutters

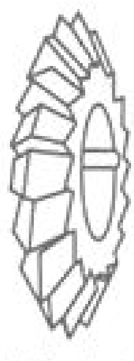
- These cutters carry sharp Angular teeth which are neither parallel nor normal to their axes.
- Their specific use is in milling V-grooves, Notches, Dovetail slots, Reamer teeth and other Angular surfaces.

The following two types of Angle Cutters are in common use:

1. *Single Angle Cutters*: These cutters may have their teeth either only on the angular face or on both, the angular face and the side. The latter type enables milling of both the flanks of the included angular groove simultaneously. Their teeth may have an included angle of 45° or 60°



Single Angle Cutter.



Double Angle Cutter.

2. *Double-Angle Cutters*: These cutters differ from the single angle Cutters in that they have two angular faces which join together to form V-shaped teeth. The included angle of this 'V' is

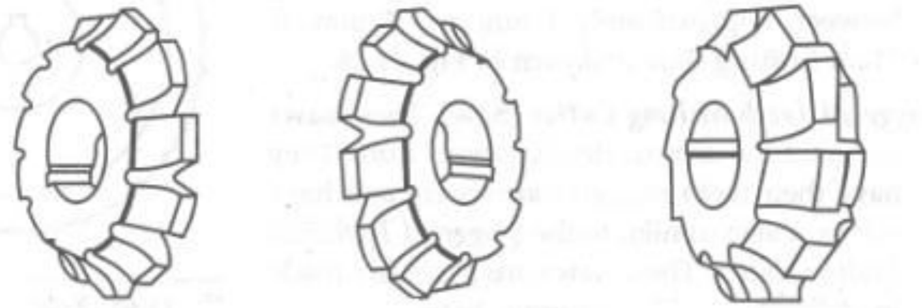
either 45°, 60° or 90°, though it is not necessary that the angle of both the faces should be equal.

Form Milling Cutters

- They are also known as Form relieved Milling Cutters or Radius Cutters.
- This category includes a fairly large variety of milling cutters used for producing different shaped contours.
- Their teeth are proved with a certain angle of relief so that their form and size are retained even after resharpening.

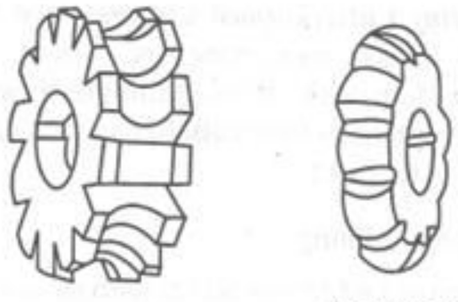
The following are the common types of Form Relieved Cutters.

1. <u>*Corner Rounding Cutters*</u>: These cutters are used for milling the edges and corners of the jobs to a required radius. They are manufactured separately as Single cutters or Double cutters. Single cutters are right hand or Left hand. The double cutter has a combination of both right hand and left hand in a single unit.



R.H. Corner rounding cutter. L.H. Corner rounding cutter. Double rounding cutter.

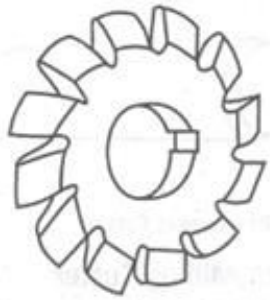
2. <u>*Concave and Convex Cutters*</u>: These cutters are very commonly used types of Form Relived Cutters. They are used for milling Convex and Concave surfaces or Circular Contours of half circle or less. The above names sometimes mislead. It should, therefore, be carefully noted that the names Concave or Convex, given to the cutters, do not indicate the shape of the surface to be produced but the shape of the cutter teeth. As such a Concave Cutter will be used for milling a convex surface and a convex cutter for milling a Concave surface.



A Concave Cutter. A Convex Cutter

3. <u>*Gear Cutters*</u>: They are also designed as Involute Gear Cutters. They are used for milling gear teeth on a Milling machine. The two common grades are Roughing and Finishing, shown in figure.

A Form relieved Gear Cutter (roughing).



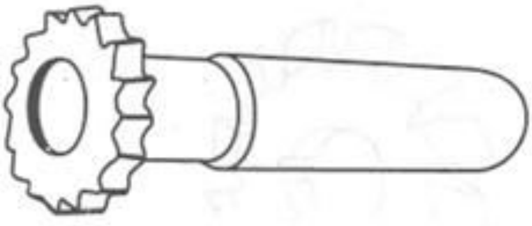
A Form relieved Gear Cutter (finishing).

4. *Tap and Reamer Fluting Cutters*: These formed cutters are used for milling flutes on Reamers and Taps. In appearance, they look like Double Angle Cutters, such that their two inclined faces meet to form a rounded corner. A typical Tap and Reamer Fluting Cutter is shown in figure.

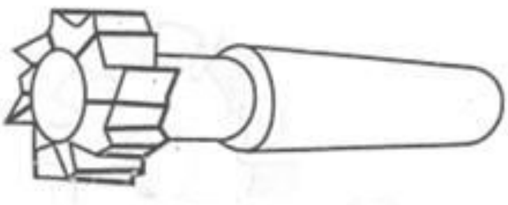
Tap and Reamer Fluting Cutter.

5. *Thread Milling Cutters*: These are also formed cutters used for milling different types of threads, mostly for Worms and Acme type Threads. These cutters can be single or multi-teeth. The included angle of the cutting teeth will correspond to the angle of the threads to be produced

Woodruff-Key and T Slot Milling Cutter



A Woodruff key-seat Cutter.



A T-slot Milling Cutter

- *Woodruff key* is small type of end milling cutter which resembles with plain and side mills.
- Smaller sizes, say up to 50 mm diameter, are made to have solid shank, to be fitted in the machine spindle, whereas the larger sizes are provided with a hole for mounting the same on an arbor.
- Smaller sizes generally have straight teeth on the periphery with the sides having a little clearance.
- Larger sizes are usually made to have staggered teeth both on the periphery as well as the sides. A small size Woodruff-key Milling Cutter is shown in figure.

T-Slot-Milling Cutter is a single-operation Cutter which is used only for cutting T-slots.

- In smaller sizes it is made to have the shank integral with the cutter, as shown in figure.
- Large size cutters are mounted on a separate shank.
- In operation, the narrow groove at the top is first milled by means of a slotting cutter or end milling cutter.
- The T-slot milling cutter is then employed for milling the wider groove.
- Note the thin neck provided between the shank and the cutter.
- It facilitates an unhindered movement of the cutter through the upper groove as the cut proceeds.

Fly Cutter

- It is actually a single point Tool. It is either mounted on a cylindrical body held in a stub arbor or held in a bar exactly in the same way as a boring tool in a boring bar.
- Screws are used for tightly holding the tool in the above holders.
- Cutting edge of the tool can be ground to any desired shape.
- It can, thus, be considered as a formed tool.
- It is generally used for experimental purposes since such a cutter, if properly designed, is capable of producing a very accurate surface.

Materials for Milling Cutters

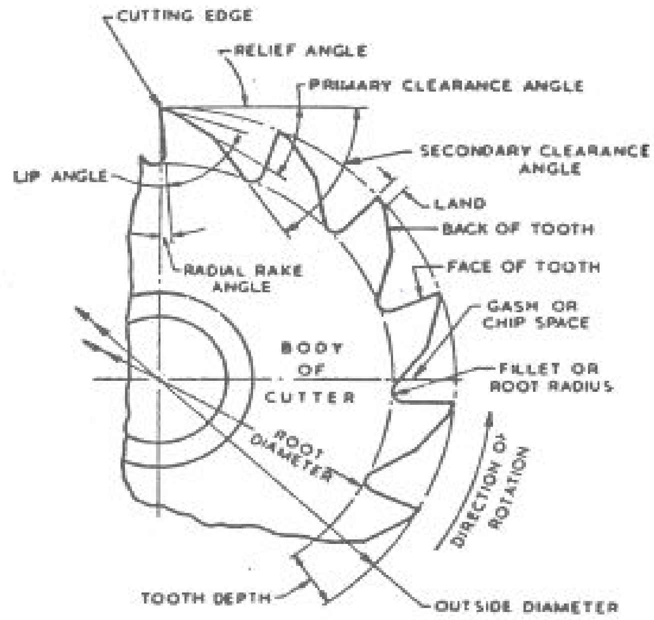
Materials used for the manufacture of Milling Cutters are the same as for Lathe Tools. The Common materials used for this purpose are :

* High Carbon Steel * High Speed Steel
* Stellite * Cemented Carbides
* Ceramics

High Carbon Steel is not very commonly used for this purpose except for a few cutters used for small scale production. High Speed Steel is a very extensively used material for most of the Solid Types Cutters. The common High Speed Steel for this purpose is the one having 18% Tungsten as those possessing a higher percentage of Tungsten are very brittle. Stellite is a very useful material for milling cutters, particularly when machine Hard metals, forgings and casting, etc. Cemented Carbides are very commonly used materials for milling cutters when higher speeds are to be employed. Carbides are generally used in the form of Bits inserted in the carbon steel shanks, forming the Inserted Teeth Cutters. Just like carbide tips, tips made from Ceramics are also used in milling cutters; their specific use being on bronze and cast iron etc. With these, the operation can be performed at twice the speeds employed for cemented Carbide Tipped Tools. However, on account of their extreme brittleness their use is confined to finishing operations only. For the same reasons they are not used where intermittent or heavy cuts are employed.

Elements of a Plain Milling Cutter

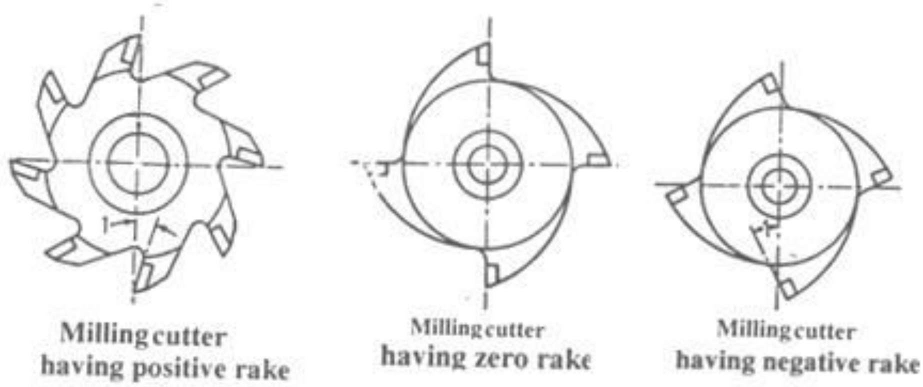
The principal parts and angles of a plain milling cutter illustrated in figure are described below:



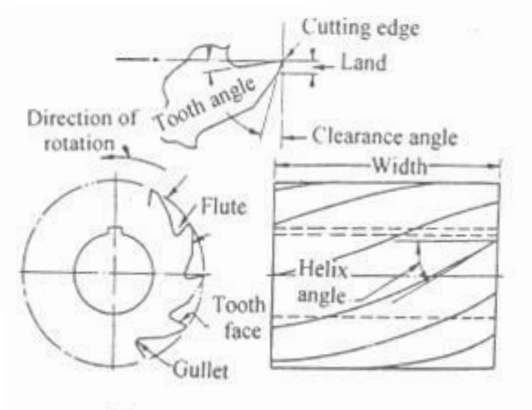
Elements of plain milling cutter

Body of Cutter: The part of the cutter left after exclusion of the teeth and the portion to which the teeth are attached.
Cutting edge: The edge formed by the intersection of the face and the circular land or the surface left by the provision of primary clearance.
Face: The portion of the gash adjacent to the cutting edge on which the chip impinges as it is cut from the work.
Fillet: The curved surface at the bottom a gash which joins the face of one tooth to the back of the tooth immediately ahead.
Gash: The chip space between the back of one tooth and the face of the next tooth.
Land: The part of the back of tooth adjacent to the cutting edge which is relieved to avoid interference between the surface being machined and the cutter.
Lead: The axial advanced of the helix of the cutting edge in one complete revolution of the cutter.
Outside diameter: The diameter of the circle passing through the peripheral cutting edge.
Root diameter: The diameter of the circle passing through the bottom of the fillet.

Cutter angles: Similar to a single point cutting tool, the milling cutter teeth are also provided with rake, clearance and other cutting angles in order to remove metal efficiently. The following are the different cutter angles.
Relief angle: The angle in a plane perpendicular to the axis, which is the angle between the land of a tooth and the tangent to the outside diameter of cutter at the cutting edge of that tooth.
Primary clearance angle: The angle formed by the back of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.
Secondary clearance angle: The angle formed by the secondary clearance surface of the tooth with a line drawn tangent to the periphery of the cutter at the cutting edge.
*Rake angle (Radial)***:** The angle measured in the diameter plane between the face of the tooth and a radial line passing through the tooth cutting edge. The rake angles which may be positive, negative or zero are illustrated in figures.



Zero rake: If the radial line and tooth face coincide in the diameter plane, the rake angle is zero.
Positive rake: If the tooth face is titled, so that the face and the tooth body are on the same side of the radial line, then the rake angle contained by the radial line and the tooth face is positive.
Negative rake: If the tooth face is titled, so that the face and the tooth body are on the opposite side of the radial line, then the rake angle contained by the radial line and the tooth face is negative.
<u>*Axial rake angle (for helical teeth):*</u> The angle between the line of peripheral cutting edge and the axis of the cutter when looking radially at the point of intersection.
<u>*Lip angle*</u>**:** The included angle between the land and the face of the tooth, or alternatively the angle between the tangent to the back at the cutting edge and the face of the tooth
<u>*Helix angle*</u>**:** The cutting edge angle which a helical cutting edge makes with a plane containing the axis of a cylindrical cutter. Figure illustrates the helix angle of a helical cutter.

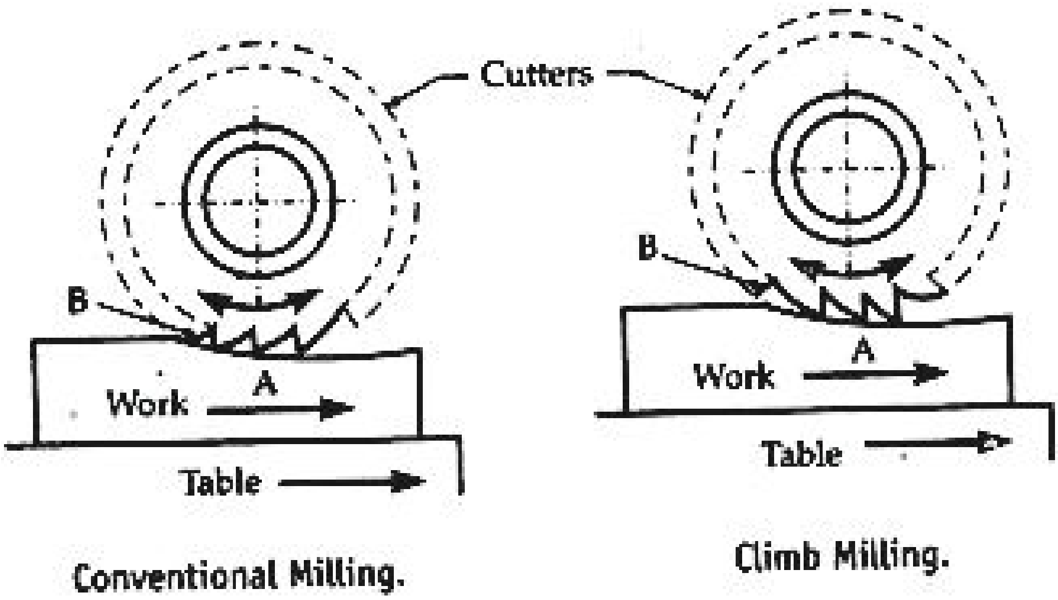


Helix angle of helical cutter

Milling Methods

Milling as has already been stated is a process of metal cutting by means of a multi-teeth rotating tool, called cutter. The form of each tooth of the cutter is the same as that of a single point tool. However, an important feature to be noted is that each tooth, after taking a cut, comes in operation again after some interval of time. This allows the tooth to cool down before the next cutting operation is done by it. Obviously this minimises the effect of heat developed in cutting on the cutting edge. With Cylindrical cutters, the following two methods are commonly used for performing this operation.

Up or Conventional Milling: In this method of milling the cutter rotates in a direction opposite to that in which the work is fed (see figure)



Down or Climb milling: In this method the direction of rotation of the cutter coincides with the direction of work feed, as shown in figure.

- The above relative directions of movements of the cutter and work should be noted at the point of contact between the two.
- On comparing the above methods, it find that the shape of chip (shaded area between points A and B) removed by the cutter in both the cases is the same, but an important difference is that in conventional Milling as the cut proceeds, the chip thickness increases gradually; as from A to B.
- Against this the chip thickness decreases in case of Climb Milling. In other words we can say that the chip thickness in conventional Milling is minimum (zero) at the start of the cut and maximum at the end of the cut, whereas in Climb or Down Milling, it is a reverse case, i.e., maximum in the beginning and zero at the end.
- The selection of a particular method, of the above two, depends upon the nature of work.
- The former method, i.e., conventional Milling is commonly used for machining castings and forgings since this method enables the cutter to dig-in and start the cut below the hard upper surface.
- The second method i.e., slot cutting, milling grooves, slitting, etc. It gives a better surface finish but it should be ensured, before employing this method, that there is no backlash in the feeding mechanism of the table and the work is rigidly held.

Cutting Speed and Feed

Cutting Speed

- The Cutting speed of a milling cutter is the distance travelled per minute by the cutting edge of the cutter.
- It is measured at the circumference of the cutter and is expressed in Metres per minute or Feed per minute, depending upon that are adopted.
- Now suppose that D mm is the diameter of the cutter and it makes N revolutions per minute.
- Then, the distance travelled by its cutting edge in each revolution is equal to the circumference of the cutter, i.e., = πD mm.
- Since it makes N rpm, therefore the total distance travelled per minute = πDN mm.

or,

$$\text{Cutting Speed} = \frac{\pi DN}{1000} \text{ m / min}$$

Feed

- It represents the Table travel in any direction, measured in millimeters.
- Feed can be given to the table either by hand or through automatic means.

Whatever may be mode of feeding, it can be expressed in the following three ways:

1. *Feed per minute*. i.e., the table travel in millimetres in 1 minute in any direction. It is expressed as mm/min.
2. *Feed per tooth*. i.e., the table travel in millimetres during the period when the cutter revolves through an angle correspoinding to the distance between the cutting edges of two adjacent teeth.
3. *Feed per revolution*. i.e., the table travel in millimetres during the period when the cutter makes one full revolution. It is expressed in mm/rev.

   It will be interested to note that:

Feed per revolution = Feed per tooth x T Where T = no. of teeth in the cutter.

and,	Feed per min = Feed per revolution x N
where, N = no. of revolutions per min of the cutter.	

i.e.,	Feed per min = Feed per tooth x T x N

Estimating Machining Time

The following factors are to be considered in Estimating the Machine time in any type of milling operation:

1. Total length of job to be machined.
2. Approach i.e., the distance through which the cutter has to move before the full depth of cut is acquired.
3. Over run i.e., the distance through which the cutter has to move further, after the job length is over, ot be clear of the job.
4. Number of cuts.
5. Cutting speed.
6. The amount of feed per minute.

Figures show Milling Operations being performed by using the plain and face milling cutters respectively.

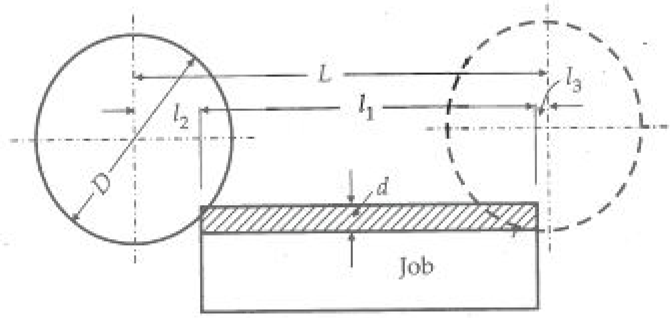
Let

l_1 = Length of the job to be machined in mm.

l_2 = Approach in mm

l_3 = Overrun of the cutter in mm.

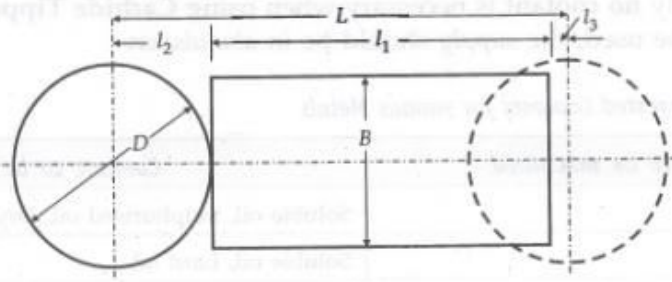
If L be the total distance of table or cuter travel, then:



Plain Milling.

If *L* be the total distance of *table* or *cutter travel*, then :

$$L = l_1 + l_2 + l_3$$



Face Milling.

Now, in Plain Milling, if D mm be the diameter of the cutter and d mm be the total depth of the cut, then the approach l_2 is given by:

$$l_2 = \sqrt{d(D-d)}$$

In Face Milling; let b mm be the width of the Job D mm the diameter of the cutter, then the Approach in this case is given by :

$$l_2 = 0.5\left(D - \sqrt{D^2 - b^2}\right) mm$$

The Overrun of the cutter, depending upon the size of the machined surface, can be taken from 1 to 6 mm.

Now, if n be the number of cuts and f the feed in mm per minute, then the Machining Time T in minutes can be calculated from :

$$T = n \text{ x } \frac{L}{f \text{ x } N} \text{ minutes}$$

For finding out the Total Floor Time, Handling time should be added to the actual Machining time calculated above.

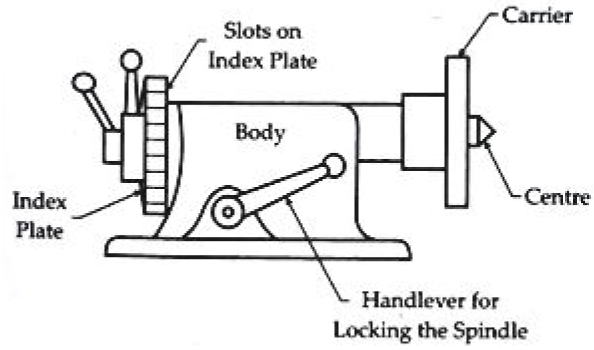
Indexing or Dividing Heads

These Heads help in changing the angular position of the component in relation to the cutter. With their use, it is possible to divide the periphery of the work piece into any number of equal parts. These Heads are generally of the following three types:

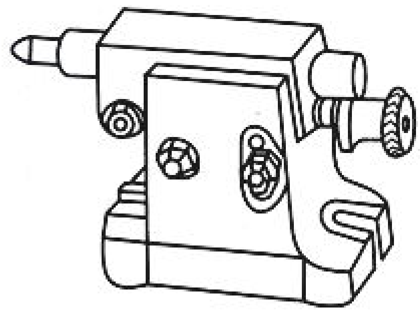
- Plain Dividing Head
- Universal Dividing Head
- Optical Dividing Head

Out of these, the last one i.e., Optical dividing head is the most precision attachment and is, therefore, used for very precision Indexing work or for checking the Indexing accuracy of the other types of Dividing heads.

Plain Dividing Heads

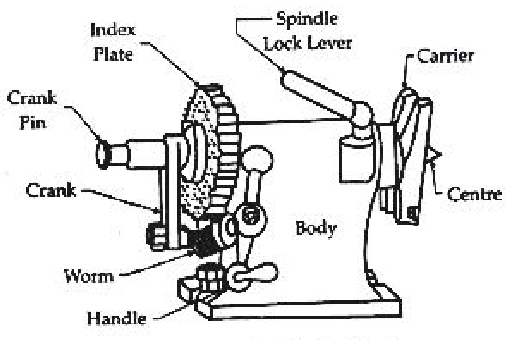


(a)



(b)

- These Dividing Heads are mainly of two types.
- The first type carries the Indexing Plate directly mounted on its Spindle and has no use of the worm, and worm wheel.
- It is the simplest of all the dividing heads and is used in Direct Indexing.
- The Index Plate carries 12 or 24 equispaced slots on its periphery. Figure (a) shows such a Dividing head.
- The job is held between two centers, one on the Dividing head Spindle and the other on the Tailstock (Figure (b)).
- The Head lever is used for locking the spindle in position. In operation, a lug engages the desired slot of the Indexing plate.
- By means of this Dividing heads 2,3,4,8 and 24 divisions can be obtained when 24 Slots Plate is used and 2,3,4,6 and 12 divisions when a 12 Slots plate is used.
- The Plate, together with the spindle, can be rotated by means of the Handle provide on the left side of the Dividing head.



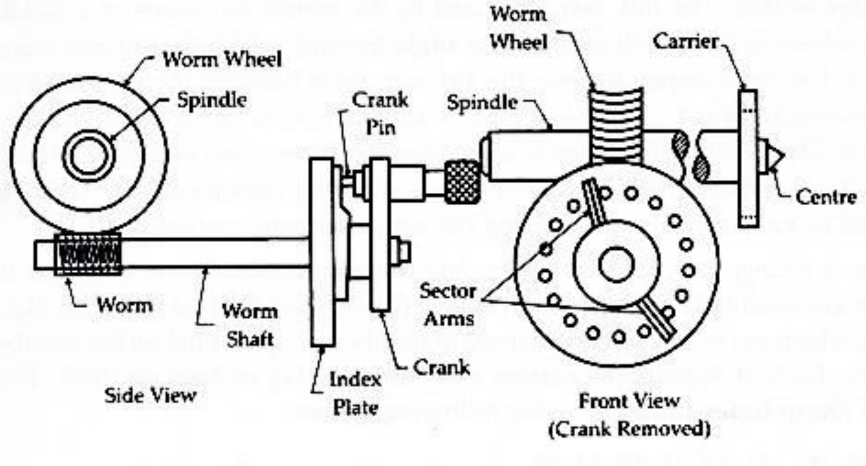
Plain Indexing Head.

- Another useful form of the Plain Dividing Head is the one used in simple indexing (see figure).
- It consists of a cast body, carrying the spindle. On the front end of the spindle are mounted the carrier and the centre. On its rear side is mounted the Index Plate, which is having different hole circles on its face and Teeth on its periphery.
- The plate gets movement through a worm by rotating the handle.

- The crank, carrying the pin, is mounted on a bolt about which it can be swung to any desired position to bring the pin in front of the desired hole.
- Usually, Plates having 3 circles of 16, 42 and 60 or 24, 30 and 36 holes are provided on these Heads.
- Other plates of different hole circles may also be available in the market.
- The job is held between centers are usual.

Universal Dividing Head

This type of Dividing Head is a very useful device for the purpose of Indexing work.
It essentially consists of a fairly robust Body. Enclosed in it is the Worm drive, which consists of a Worm and Worm wheel.
Details of this internal mechanism are shown in figure.
The dividing head spindle carries a Worm wheel, as shown.



Internal mechanism of Universal Dividing Head.

- The spindle carrying the worm, which meshes with the worm wheel, carries a crank at its outer end.
- The Index pin works inside the spring loaded Plunger.
- This Plunger can slide radially along a slot provided in the crank in order to adjust the pin position along a desired hole circle on the index plate.
- The Index plate is also mounted on the same spindle as the crank, but on a sleeve such that the work spindle, and hence the crank, can move independent on the Index plate.
- The sector arms provided on the Index plates are usually of detachable type and can be set at a desired angle with one another in order to set a definite distance along a desire hole circle.
- The index plates are available in a set of two or three with a number of hole circles usually on both sides on them.
- The spindle, carrying the worm wheel is provided with a job carrier (driving device) and a centre at its front end.
- On the back side of the Dividing head is provided a Bracket which carries a slot along its length.
- One or two studs, according to requirement, ca be fitted in this slot and predetermined set of change gears can be mounted on them.

The Universal Dividing Head performs the following operations:

- It sets the work piece in a desired position in relation to the machine table.
- After each cut, it rotates the job through a desired angle and, thus, indexes the periphery of the work.

- It provides a continues rotary motion to the job during milling of helical grooves.
- It, in conjunction with a Tailstock, acts both as a holding as well as supporting device for the work during the operation.

Using the Dividing Head

- As described above, the Dividing Head provides support to the job, holds it in position and rotates it through a desired angle after each cut is over.
- The index crank is rotated to provide the rotary motion to the job and the index plate enables this rotation to take place always through a desired angle.
- When the Crank is rotated, the worm rotates which, in turn, rotates the worm wheel.
- Since this wheel is mounted directly on the spindle the latter rotates along with for former.
- The job, being secured to the spindle by means of a suitable holding device, also rotates as the spindle rotates.
- The angle through which the job will rotate, for each revolution of the crank, depends upon the Velocity ratio between the worm and worm-wheel.
- This ratio is usually 40 to 1, i.e., for 40 revolution of the crank, the job will make one revolution.
- Obviously, if the Worm is single start the Worm wheel will have 40j teeth along its periphery.
- However, some Dividing Heads carry a different velocity ratio of these two and the same should be known before performing the actual Indexing operation.
- A set of change gears can be incorporated to connect the Worm shaft and the spindle.
- These gears are mounted on the left hand side of the Dividing head.
- The Index plates, which are normally two or three in number, are provided with a number of circles on each face. Each of these circles carries a definite number of holes on them.
- The standard brown and sharp index plates have the following circles :

  No. 1. 15,16,17,18,19,20. *No. 2*. 21,23,27,29,31,33.
  No. 3. 37,39,41,43,47,49.

Indexing Methods

By Indexing we mean division of the job periphery into a desired number of equal divisions. It is accomplished by a controlled movement of the Crank such that the Job rotates through a definite angle after each cut is over. The following methods of Indexing are commonly used :

- Direct-indexing
- Plain or Simple Indexing
- Compound Indexing
- Differential Indexing
- Angular Indexing

Direct Indexing

- It is the simplest case of indexing in which a plain dividing head is used.
- The Index plate is directly mounted on the spindle and rotated by hand.
- It can be used only when the number of divisions to be obtained is such that the number of slots on the periphery of the index plate is a multiple of the former.

The Indexing ratio is obtained by : Required ratio = $\frac{N}{n}$

where, N = No. of slots on the periphery of the index plate
and n = No. of divisions required to be obtained.

For example, if the circumference of a job has to be divided into 6 equal divisions and the Index plate has 24 slots, then the required ratio will be :

$= \frac{24}{6} = \frac{4}{1}$, i.e., the index plate will be required to move through 4 slots after each cut is over.

Plain or Simple Indexing

- This method of Indexing is used when the direct method of indexing cannot be employed for obtaining the required number of divisions on the work.
- For example, if the work is required to be divided into 22 equal divisions the direct indexing cannot be used, because 22 is not divisible into any of the hole circles on the direct Indexing Plate. For such cases, Simple Indexing can easily be used.
- For this, either a plain indexing head or a universal dividing head can be used.
- This method of indexing involves the use of the crank, worm, worm wheel and index plate.
- As already described, the Worm wheel carries 40 teeth and the Worm is single start.
- The worm wheel is directly mounted on the spindle.
- When the crank pin is pulled outwards and the crank is rotated, the worm will rotate which, in turn, will rotate the worm wheel, and hence the spindle and the work.
- Since the worm has single start thread and the worm wheel 40 teeth with one turn of the crank (i.e., of the worm) the worm wheel will rotate through one pitch distance, i.e., equal to 1/40 of a revolution.
- Similarly 2 turns of crank will make the work to rotate through 1/20 and 3 turns through 3/40 of a revolution.
- Thus, the Crank will have to be rotated through 40 turns in order to rotate the work through one complete turn.
- The holes in the Index plate serve to subdivide the rotation of the Index crank.

Now suppose we want to divide the work into a number of divisions, the corresponding crank movements will be as given crank :

For two divisions on the work, the Crank will make $\frac{40}{2}$ = 20 turns for each division

For four divisions on the work, the Crank will make $\frac{40}{4}$ = 10 turns

For ten divisions on the work, the Crank will make $\frac{40}{10}$ = 4 turns

Similarly for n divisions on the work, the Crank will make $\frac{40}{n}$ turns

Let us consider that the work has to be divided into 23 equal divisions, then the corresponding crank movement will be given by :

Crank movement = $\frac{40}{23} = 1\,\frac{17}{23}$ *turns*

- Now, in the obtained result, the whole number indicates the number of full turns the crank has to move through, and the fraction represents the port of the turn that the crank has to make, in addition to the above, in order to make the work to rotate through one required division, i.e., 17/23 of a revolution.
- In the fraction, the numerator denotes the number of holes to be moved and the denominator the number of holes on the circle to be used.
- Thus, for the above indexing, for each division on the job, the Crank will make one complete revolution and will move further through 17 holes on 23 holes circle.

Compound Indexing

This method of Indexing is employed when the number of divisions required is outside the range that can be obtained by simple indexing. It involves the use of two separate simple indexing movements and is performed in two stages:

1. By turning the Crank a definite amount in one direction in the same way as in simple indexing.
2. By turning the Index plate and the Crank both, either in the same or reverse direction, thus adding further movement to or subtracting from that obtaining in the first stage.

<u>Principle of Compound Indexing</u>

<u>Example 1:</u>

- The principle of Compound Indexing can be best illustrated by taking a concrete example.
- Let us consider that the crank is turned 3 holes on a 18 holes circle and the index plate and crank both turned further 5 holes on 20 holes circle.
- On account of these two movements the Worm will be turned through :
- $\frac{3}{18} + \frac{5}{20} = \frac{5}{12}$ *of a revolution.*
- Since 40 turns of the Worm turn the Work through 1 revolution. Therefore, $\frac{5}{12}$ turn of the worm will turn the work through $\frac{5}{12\times40}$ revolution

  i.e., $=\frac{1}{96}$ of a revolution.
- This will enables 96 divisions on the work.

<u>Example 2:</u>

- Similarly, let us consider another case, where in the second operation the index plate and the crank are rotated in a reverse direction to that adopted in the first operation.
- Suppose the Crank is turned 5 holes on the 18 holes circle in one direction and then the Index plate, along with the crank, turned 2 holes on 20 holes circle in a direction opposite to the former.
- On account of these two movements the worm will be turned through :

  $\frac{5}{18} - \frac{2}{20} = \frac{64}{360} = \frac{8}{45}$ of a revolution.
- Now, the corresponding movement of the work will be

  $=\frac{8}{45} \times \frac{1}{40} = \frac{1}{225}$ of a revolution.
- Thus, 225 divisions can be obtained on the work.

<u>Procedure</u>

In order to obtain the required number of divisions through Compound Indexing proceed as follows:

1. Factorise the number of divisions required.
2. Factorise the standard No. 40.
3. Select for trial any two circles on the same plate and on its same side.
   Factorise their difference.
4. Factorise the number of holes of one circle.
5. Factorise the number of holes of the other circle.

After obtaining these factors place them as follows :

$$\frac{Factors\ of\ divisions\ required\ \times Factors\ of\ difference\ of\ hole\ circles}{Factors\ of\ 40\ \times Factors\ of\ first\ circle \times Factors\ of\ second\ circle}$$

First Check

If suitable index circles have been selected then all factors in the numerator will be cancelled by those in the denominator. That is, you will get unity in the numerator. If it does not happen, select another set of circles and made another attempt in the same way as above. Repeat it till you get 1 in the numerator.

Now, suppose the above expression, after simplification, comes to the form 1/X, where X may be any number. If a and b denote the numbers of holes on the two circles, then the required Indexing Movement will be given by :

$$\frac{X}{a} - \frac{X}{b} \text{ or } \frac{X}{b} - \frac{X}{a}$$

The positive part of the two indicates the movement of the crank in one direction and the negative part denotes the movement of plate and crank in the opposite direction. It is always advisable to keep the backward motion as smaller of the two.

Second Check

After finding the above two expressions, check that the algebraic sum, of the two movements, i.e., of the Crank in one direction, and that of the Crank and Plate in the opposite direction, should be equal to 40/N, where N is the number of divisions required. Or, we can say that, if the correct result is obtained, them :

$$\frac{X}{a} + \frac{X}{b} = \frac{40}{N}$$

Differential Indexing

- In principle it is not very much different from compound indexing.
- It is also carried out in two stages. First the Crank is moved in a certain direction. In the second operation that follows, either some movement is added to the above crank, movement or subtracted from the same.
- However, it should be noted that the said loss or gain in the movement is accomplished by moving the plate by means of a train of gears, connecting the dividing head spindle to the worm spindle.
- The said motion is gained by rotating the index plate in the same direction as crank and it is lost by rotating the plate in the opposite direction to that of the crank.
- During differential indexing the index plate locking pin should be taken out to make the Plate free to rotate.
- The dividing heads are supplied with standard sets of change gears. Change gears supplied with brown and sharp dividing heads are the following:

  24(2 Nos.), 28, 32, 40, 44, 48, 56, 64, 72, 86, 100

  In addition to this, some dividing heads are provided with the following gears also:

  46,47,52,58,68,76,84.

The German made Universal Dividing Heads, referred to earlier, are provided with the following set of gears.

24(2), 28, 32, 40, 44, 48(2), 56, 64, 72, 86, 96, 100

Both Simple and Compound gear trains are used in differential indexing. In these gear trains the first driver is always mounted on the main spindle of the dividing head, i.e., the same spindle on which is mounted on the worm wheel inside and job at the other end. The last driven is mounted on the worm spindle which drives the index plate. The simple train consists of only one driver and one driven, connected together through one or two idle gears.

Example:

Find the Gear Combination and Indexing movement necessary for 139 divisions

Solution: For this, let us select a number slightly greater or smaller than the given number, such that the selected number can be easily indexed through simple indexing. Let us select the new number as 140.

Simple indexing for 140 divisions = $\frac{40}{140} = \frac{2}{7} = \frac{6}{21}$

i.e., 6 holes on 21 holes circle.

Now, if the Index crank is turned $\frac{6}{21}$ of a revolution 139 times, it will make:

$$\frac{6}{21} \times 139 = 39\frac{15}{21} \text{ revolutions}$$

Whereas, for one complete turn of the job it should make 40 complete revolution. Obviously, the job would not be, thus, indexed through exactly 139 equal divisions. The total movement done by the crank is short of the required 40 turns by:

$$40 - 39\frac{15}{21} = \frac{6}{21} \text{ of a revolution.}$$

This fraction is to be gained by the movement of the plate. In order to gain the movement the plate will have to be turned in the same direction as the Crank. Also, in order than the divisions are equal, this movement is to be gained gradually such that a certain amount of it is added equally to the Crank movement in all the 139 movements of the latter, so as to make it complete 40 turns at the end of these movements. This will be done by employing a suitable Gear train.

Now, the Gearing ratio = $\frac{6}{21} = \frac{2\times3}{3\times7} = \frac{32\times24}{48\times56} = \frac{drivers}{driven}$

i.e., { First driver 32 teeth, First follower 48 teeth
Second driver 24 teeth, Second follower 56 teeth }

Since it is a compound train and the motion is to be gained, no idler is required.

Angular Indexing

It is noted that for 40 turns of crank make the work rotate through one complete turn. That is, 40 turns of Crank make the work to rotate through 360°. Therefore, for each one turn of the Crank the work will rotate through $\frac{360}{40} = 9°$.

Now let us consider 18 holes circle.
If the Crank is moved through 18 holes on 18 holes circle,
i.e., one turn, it will make the work to turn through 9°.
If it is moved 9 holes, i.e., half turn on this circle, the work will rotate through half the above angle i.e., $\frac{9}{2} = 4\frac{1}{2}°$.
Again if it is moved 2 holes on this circle, i.e., 2/18 or 1/9 of a turn, the work will rotate through 9/9=1°.

Similarly, if the Crank is moved only one space on 18 holes circle, the job will rotate through $9\times\frac{1}{18} = \frac{1}{2}{}^{\circ}\ or\ 30°$.

Thus, we conclude that:

1 turn of Crank will rotate the work through 9°, 1/9 turn through 1°, 2/9 turn through 2°, 3/9 through 3° and so on.

or, Crank Movement = $\frac{Angle\ required}{9}$

Learning Material

Metal Cutting and Machine Tools

UNIT – 6

Objective:

- To familiarize with the working principle of Grinding, Broaching, Lapping and Honing processes.

Syllabus:

Grinding & Lapping and Honing

Grinding: Theory of grinding , characteristics ,classification of grinding machines ,grinding wheel, specification and selection of a grinding wheel ,methods of grinding ,cutting speed, feed, depth of cut and machining time calculations.

Lapping and Honing : Working principle ,comparison of lapping, honing and grinding.

Learning Outcomes:

Student will be able to

- Use the working principle of grinding machine to finish the different surfaces.
- List the different types of grinding machines.
- Specify the grinding wheel
- Differentiate grinding with lapping, honing and broaching.

Introduction

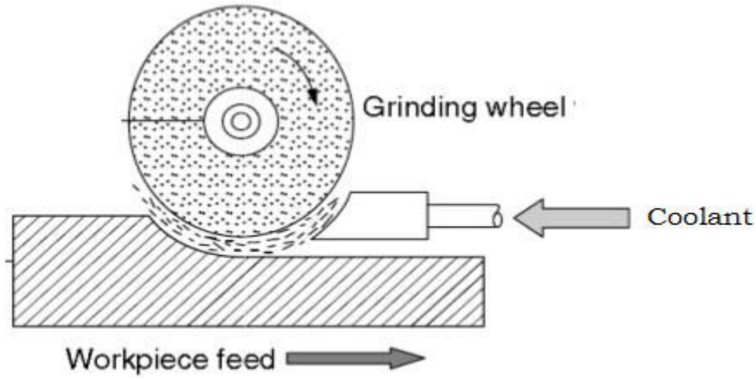
Grinding is a process of removing material by the abrasive action of a revolving wheel on the surface of a workpiece, in order to bring it to the required shape and size. So far as the cutting action is concerned, grinding is very much similar to the other machining operations since the microscopic examination of the removed material reveals that the same is in the form of small chips, similar to those obtained in other machining operations. The wheel used for performing the grinding operation is known as 'Grinding Wheel'. It consists of sharp crystals, called *abrasives*, held together by a binding material or bond. The wheel may be single piece or solid type or may be composed of several segments of abrasive blocks joined together. In most cases, it is a finishing operation and a very small amount of material is removed from the surface during the operation.

Mostly grinding is the finishing operation because it removes comparatively little metal, 0.25 to 0.50mm in most operations and the accuracy in dimensions is in the order of 0.000025 mm. Grinding is also done to machine materials which are too hard for other machining methods that use cutting tools. Many different types of grinding machines have now been developed for handling various kinds of work to which the grinding process is applicable.

Working Principle

Grinding is a material removal and surface generation process used to shape and finish components made of metals and other materials.

The precision and surface finish obtained through grinding can be up to ten times better than with either turning or milling.



- The *grinding wheel mounted on the spindle* is rotated at high speed and the *work mounted on the table* of the machine is fed against the rotating wheel.
- Grinding employs an *abrasive product*, usually a rotating wheel brought into controlled contact with a work surface.
- The grinding wheel is composed of abrasive grains held together in a binder. These abrasive grains act as cutting tools, removing tiny chips of material from the work.
- As these abrasive grains wear and become dull, the added resistance leads to fracture of the grains or weakening of their bond.
- The dull pieces break away, revealing sharp new grains that continue cutting.

Types of Grinding Machines

Various different types of grinding machines have been designed and are being used. Some of these are for roughing work, some are for precision work and some are for special purpose, i.e., to perform a specific type of operation. The varieties of grinding machines are probably larger than any other type of machine tools. However, the most commonly used types can be broadly classified as follows:

- Roughing or Non-precision grinders.
- Precision grinders.

Classification of Grinding Machines

The grinding machiens are classified as follows:

I. According to the quality of surface finish:

1. Roughing or non-precision grinders:
   i. Bench, pedestal or floor grinders.
   ii. Swing frame grinders.
   iii. Portable and flexible shaft grinders.
   iv. Belt grinders.
2. Precision grinders.

II. According to the type of the surface generated or work done:

1. Cylindrical grinders:
   i. Plain cylindrical grinders ii. Universal cylindrical grinders.
   iii. Centreless internal grinders.
2. Internal grinders :
   i. Plain internal grinders. ii. Universal internal grinders.

iii. Chucking internal grinders. iv. Planetary internal grinders.
v. Centreless internal grinders.

3. Surface grinders:
   i. Reciprocating table:
      a) Horizontal spindle. b) Vertical spindle.
   ii. Rotating table:
      a) Horizontal spindle b) Vertical spindle
4. Tool and cutter grinders:
   a) Universal b) Special

Roughing or Non-Precision Grinders

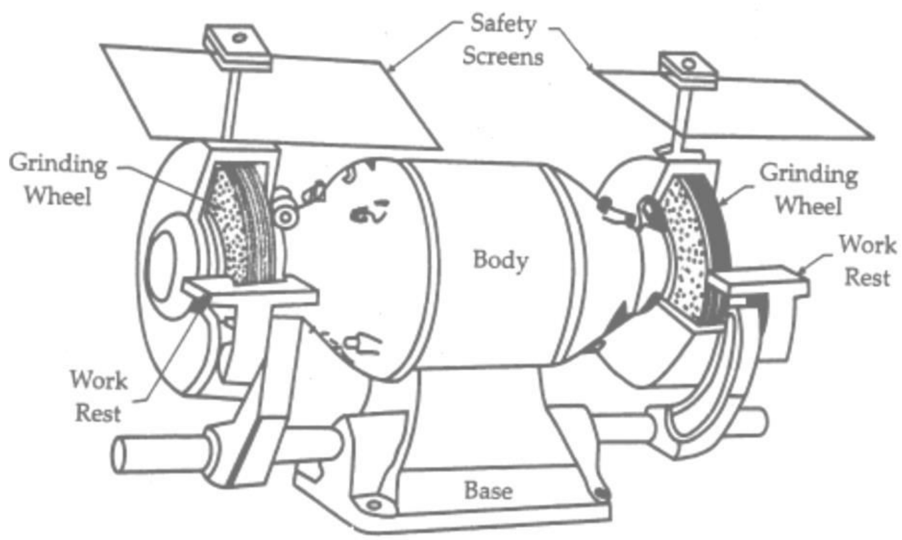
The main purpose of these grinders is to remove more stock than can be easily removed by other types of grinders. The quality of surface finish is, obviously, of a secondary importance.

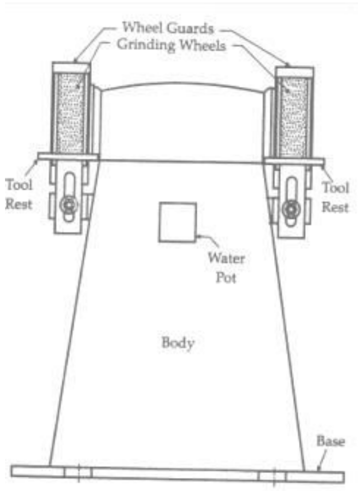
This class of grinders includes the following machines:

i. Bench, Pedestal or Floor grinders
ii. Swing frame grinders
iii. Portable and flexible shaft grinders
iv. Belt grinders.

1. **Bench, Pedestal or Floor grinders**

These grinders are commonly used for 'Snagging' and 'Off-hand' grinding of various materials and cutting tools in tool rooms, foundries and general repair shops, etc. They carry a horizontal spindle having grinding wheels mounted on both ends. A typical bench grinder is shown in figure. It can be suitable bolted on a bench at convenient height.

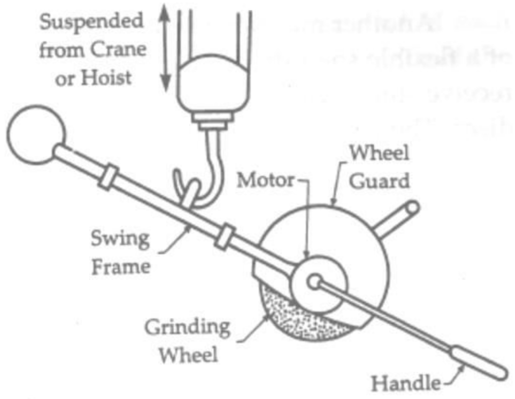




The floor stand or pedestal grinder is nothing but a bench grinder of the above type mounted on a steel stand or pedestal of suitable height. The horizontal spindle carrying the grinding wheels is normally an extension on both sides of the armature shaft of the motor. These grinders can also be used for polishing by replacing the grinding wheels by polishing wheels (See Figure.)

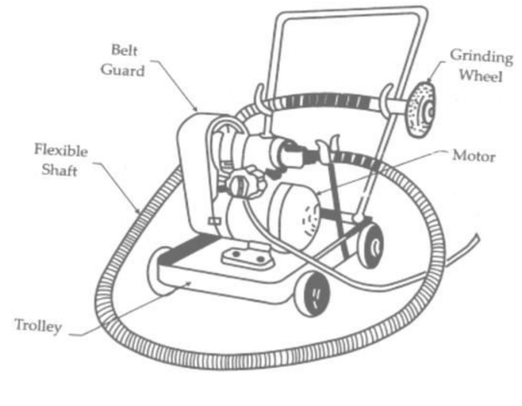
2. Swing frame grinder

It consists of a 2 to 4 metres long horizontal frame, freely suspended at its centre. The frame carries a grinding wheel at its one end and motor at the other. The motor drives the grinding wheel by means of a belt. In operation, the motor is started to revolve the wheel and the frame swung by the operator about its point of suspension (centre point) to cover up the desired grinding area (See Fig.12.11).

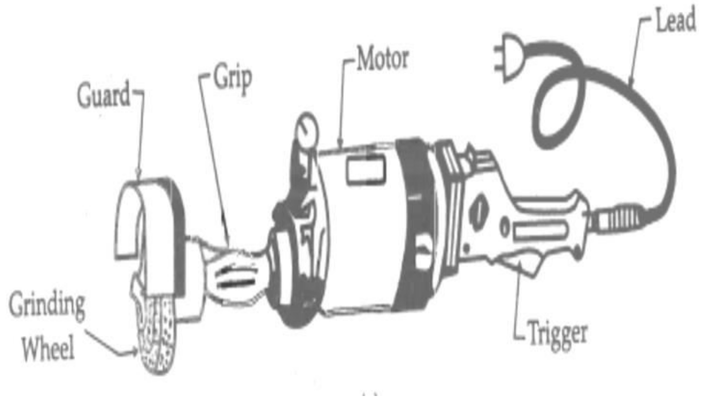


3. Portable and flexible shaft grinders

They resemble very much with the portable electric drills, both in construction as well as operation, with the only difference that the spindle carrying the drill chuck in the latter is replaced by a spindle, on which is mounted a small grinding wheel. A safety guard is also provided over the wheel. These grinders are vastly used in finishing castings, forgings, welded joints in structural work, removing burrs and sharp edges, preparing surfaces for welding by removing oxide coatings or scales, removing nicks, finishing jigs, fixtures, dies and similar other articles, where stock removal is the primary requirement and not the dimensional accuracy (See Figure).



Flexible grinder



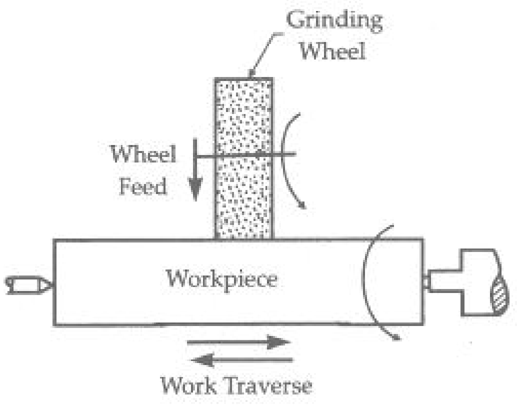
Portable Grinder

Another machine used for the same purpose is a flexible shaft grinder, which consists of a flexible shaft driven by an electric motor. The shafts carries a chuck or collect at its end to receive small grinding tools like rotary files, mounted wheels and points and small grinding discs. The electric motor is mounted on a fixed stand (See Figure).

4. **Belt grinders**

   These machines are designed to use an endless abrasive belt for grinding instead of a regular type of grinding wheel. The belt runs round the pulleys or rollers and the work is fed against the revolving abrasive coated belt. One of the roller (driver) revolves at high speed. A heavy metal plate, called platen, is so incorporated that the smooth underside of the belt runs in contact with the same. This platen may carry the shape conforming to the shape of an object or may be flat, as required. The workpiece is fed, usually manually, on to the open abrasive side of the belt and pressed against the platen to perform the grinding operation. With proper selection of proper grade and grit size, this process can be used both for rough and finish grinding. Machines are available in different varieties, like wet-belt, dry belt, combination machines, etc.

Cylindrical Grinders



The principle of cylindrical grinding, as illustrated in figure, involves holding the workpiece rigidly on centers, in a chuck or in a suitable holding fixture, rotating it about its axis and feeding a fast revolving grinding wheel against the same. If the work surface to be ground is longer than the face width of the grinding wheel, the work is traversed past the wheel or the wheel past the work. Traversing of wheel or work is done either by hydraulic or mechanical power or by hand. Feed is given to the work or the wheel at the end of each traversing movement. In case the width of wheel face is more or equal to the length of the work surface to be ground, the wheel may be fed in with no traversing movement of it or that of the work. This is known as plunge grinding. The simplest and quite commonly used type of cylindrical grinder is a tool post grinder used on lathes. When wheels of large diameters are used, they can be mounted directly on the motor shaft. For mounting small wheels an auxiliary shaft is provided, which runs at a relatively much higher speed than the motor. Both external and internal cylindrical grinding can be done on later by this equipment.

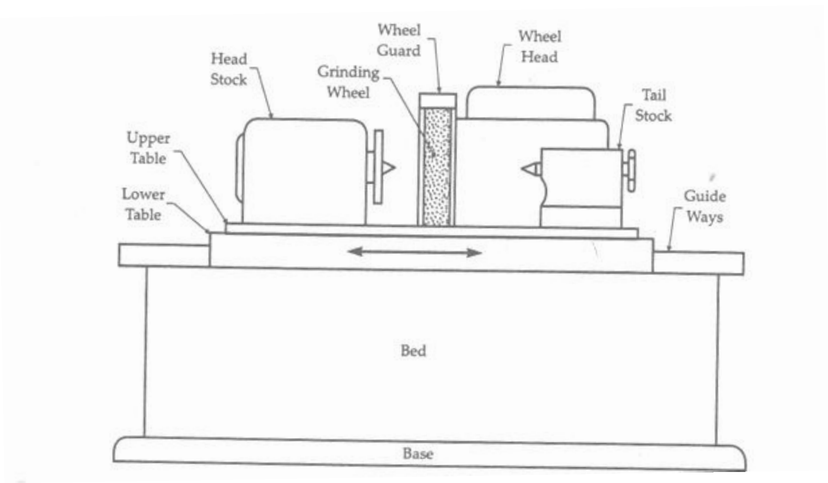
Cylindrical grinding machines are mainly of the following three types:

1. Plan cylindrical grinders
2. Universal cylindrical grinders
3. Centre less grinders.

Other forms of cylindrical grinders include roll grinders, camshaft grinders, crankshaft grinders etc. These machines differ a lot in their designs to suit the particular requirement but they all work on the common principle of cylindrical grinding, involving the following necessary basic movements:

1. The work must revolve.
2. The grinding wheel must revolve.
3. Either the wheel or the work must have a traversing movement past the other.
4. Either the wheel should be fed into the work or the work on to the wheel.

Plain Cylindrical Grinders



On these grinders, the workpiece is usually held between two centers. One of these centers is in the headstock and the other in the tailstock. In operation, the rotating work is traversed across the face of the rotating grinding wheel. At the end of each traverse, the wheel is fed into the work by an amount equal to the depth of cut. While mounting the work between centers, the head-stock centre is not disturbed. It is the tailstock centre which is moved in or out, manually or hydraulically, to insert and hold the work. Tailstock and headstock both can be moved along the table to suit the work. The table is usually made in two parts. The upper table carries the tailstock, headstock and the workpiece and can be swiveled in a horizontal plane, to a maximum of 10° on either side, along the circular ways provided on the lower table. This enables grinding of tapered surfaces. The lower table is mounted over horizontal guide ways to provide longitudinal traverse to the upper table, and hence the work. Table movements can be both by hand as well as power. Hydraulic table drives are usually preferred.

The wheel head is usually mounted on horizontal cross ways on the bed and travels along these to feed the wheel to the work. This movement is known as indeed. The wheel and work are so adjusted that the grinding force is directed downwards to ensure proper stability. A plain cylindrical grinder is shown by means of a block diagram in figure.

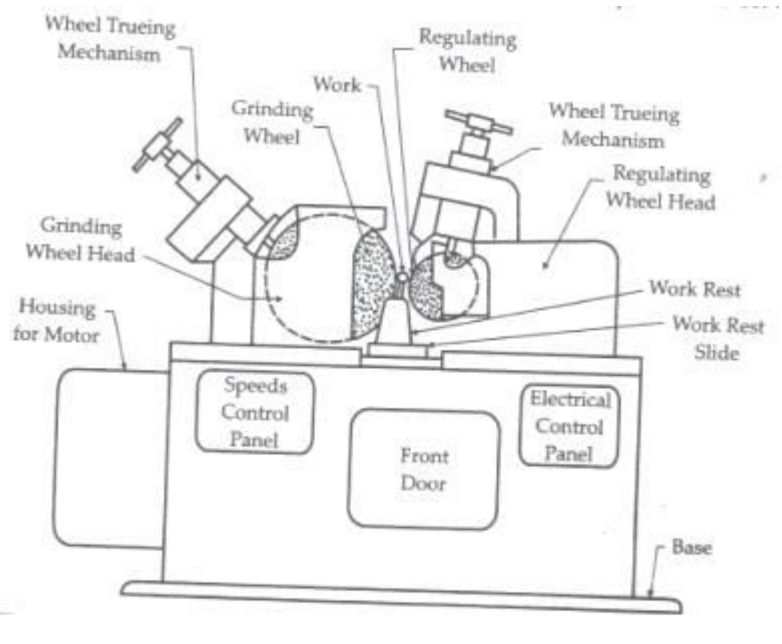
Universal Cylindrical Grinders

A Universal cylindrical grinder carries all the parts and movements of a plain cylindrical grinder and, in addition, carries the following advantages features:

1. Its headstock can be made to carry a live or dead spindle, as desired, the former being needed when the work is held in a chuck.
2. The headstock can itself be swivelled in a horizontal plane.
3. Its wheel head can be raised or lowered and can also be swivelled to ±90° to grind tapered surfaces having large taper angles.

All these factors contribute towards the greater versatility of these grinders. All the modern universal type cylindrical grinders carry hydraulic drive for wheel head approach and feed, table traverse and elimination of backlash in the feed screw nut. Most of the modern universal grinders are provided with necessary extra equipment like work rest to support slender work, wheel trueing device, arbor for balancing the wheel, internal grinding spindle and a three jaw self-centering chuck, etc.

Centreless Grinders



These grinders are also a type of cylindrical grinders only, but the principle of centre less grinding differs from centre type grinding in that the work, instead of being mounted between centers, is supported by a combination of a grinding wheel, a regulation wheel and a work rest blade. The relative movements of the work-piece and the two wheels are shown in Figure given below. The principle of centre less grinding is used for both the external grinding as well as internal grinding. Many hollow cylindrical and tapered work pieces, like bushes, pistons, valves, tubes and balls, etc., which either do not or cannot have centers, are best ground on centre less grinders.

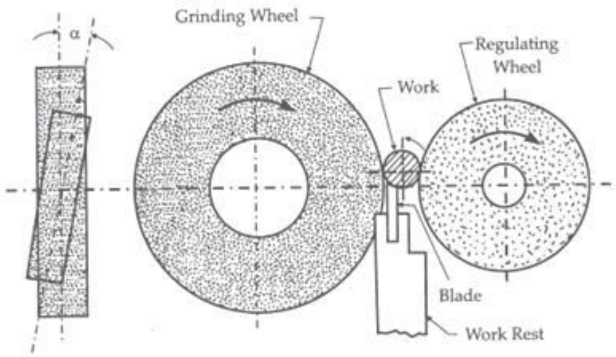
A simplified diagram of a centre less grinder is shown in above figure. Illustrating its main parts and controls. It carries a heavy base and two wheel heads, one carrying the grinding wheel (larger one) and the other regulating wheel (smaller one). The workpiece rests on the blade of the work rest between these two wheels. Each head carries a separate wheel truing mechanism for the wheel it carries. A housing is provided on one side of the machine body to house the main driving motor. There are two control panels on the front. The left hand panel carries controls for speed adjustments of the two truing mechanisms and the in feed grinding mechanism. The right hand panel carries controls for hydraulic mechanism, speed adjustment of regulating wheel, automatic working cycle switch, start and stop switches, etc.

In operation, grinding operation is performed by the grinding wheel only while the function of the regulation wheel is to provide the required support to the workpiece while it is pushed away by the cutting pressure of the grinding wheel. This helps the workpiece to remain in contact with the grinding wheel. At the same time, required support from bottom is provided by the work rest as the workpiece, while rotating, rests on the blade of the work rest. The regulating wheel essentially carries rubber bond and helps in the rotation of workpiece due to friction. The directions of rotation of the two wheels are the same. The common methods used for feeding the work are:

- Through feed
- In feed
- End feed

1. Through feed grinding

In this method of centre less grinding, the workpiece is supported and revolved as described above but is simultaneously given an axial movement also by the regulating wheel and guides so as to pass between the wheels. For this, the axis of the regulating wheel is inclined at 2 to 10 degrees with the vertical (See angle α in figure). The amount of stock to be removed determines as to how many time a workpiece has to pass between the wheels. This method is used for straight cylindrical objects.



The actual feed (f) can be determined by the following relationship:

$$f = \pi d n . \sin\alpha$$

Where f = feed in mm/min

n= revolutions/min.

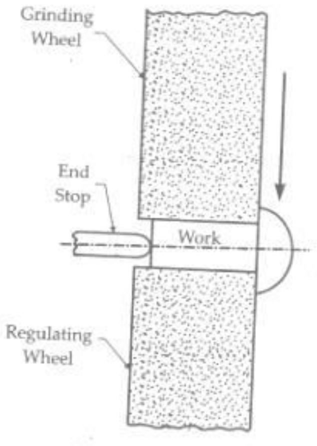
d=dia.of regulating wheel (in mm)

α = angle of inclination of regulating wheel.

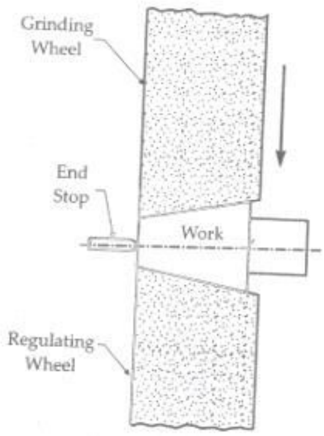
2. Infeed grinding

This method is similar to the plunge cut grinding method used on cylindrical grinders. Both regulating and grinding wheels are more in width than the work length to be ground. Axis of the regulating wheel is inclined a little, say about half a degree, from the horizontal. This method is used for grinding shouldered or formed components.

Before the operation, the regulating wheel is drawn away to accommodate the workpiece. After placing the workpiece on the blade of the workrest, the regulating wheel is again pushed in to press against the work. In this operation, the workrest does not carry guides. Instead, it is made to have an end stop at the rear end, as shown in figure.



Infeed Centreless Grinding.



End-feed Centreless Grinding.

3. End feed grinding

This method is, in a way, a sort of form grinding. It is because both the wheels, i.e., the grinding wheel and the regulating wheel, are dressed to contain the required shape or form. The workpiece is fed longitudinally from the side of the wheels. As it advances between the revolving wheels, its surface is ground till its farther end touches the end stop. This method can be used for grinding of both spherical and tapered surfaces, but it suits best to the grinding of short tapered surfaces. The method of end-feed grinding is shown in figure.

Advantages of Centre less Grinding

- The need for cantering and use of fixtures, etc., is totally avoided.
- It can be applied equally to both external and internal grinding.
- Once a set-up has been made, it is a faster method than centre-type grinding.
- In through-feed method, the process is continuous as there is no idle time for the machine, because loading and unloading is done during the operation itself.
- In feed method also no chucking of work is needed and, as such, the idle time of the machine is almost negligible.
- Since there is no end thrust, there are no chances of any springy action or distortion in long workpiece.
- The operating conditions automatically provide a true floating type centre for the workpiece and, as such, the common errors normally associated with the centres and centre holes are automatically eliminated.
- The workpiece is supported rigidly during the operation and can be subjected to heavy cuts, resulting in a rapid and more economical grinding.

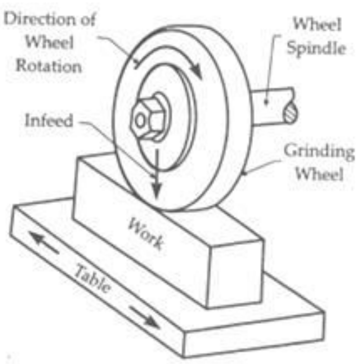
- Since the need for making and making centre holes is totally eliminated and a smaller grinding allowance is needed, the grinding time is considerable reduced.
- Large grinding wheels are used and errors due to wheel wear are reduced. So, the requirement of wheel adjustment is minimum.
- A very little maintenance is needed for the machine.
- Very highly skilled operators are not needed for operating centre less grinders.
- Direct adjustment for sizes can be made, resulting in a higher accuracy.
- A fairly wide range of components can be ground.

Surface Grinders

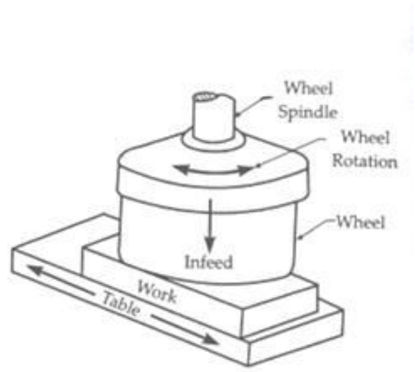
Surface grinders do almost the same operation as the planers, shapes or milling machines, but with more precision. Primarily they are intended to machine flat surfaces, although irregular, curved or tapered surfaces can also be ground on them. The common classification of surface grinders can be made as follows:

1. According to the table movement:
   a) Reciprocating table type. b) Rotary table type.
2. According to the direction of wheel spindles:
   a) Vertical spindle type.   b) Horizontal spindle type.
3. Special type and single purpose machines :
   a) Face grinders   b) Way grinders.
   c) Wet belt grinders.

Reciprocating Table Type Surface Grinders



Working principle of a Horizontal Spindle Reciprocating Table Surface Grinder.



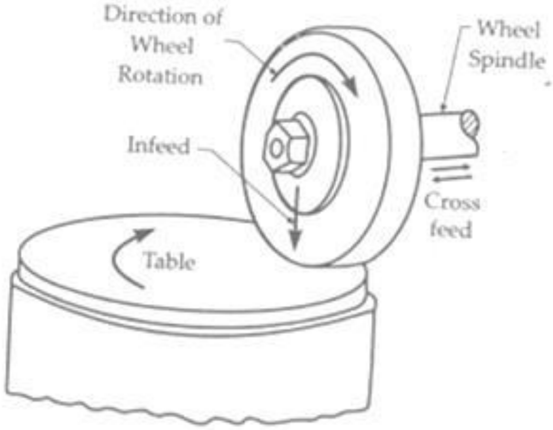
Working principle of a Vertical Spindle Reciprocating Table Surface Grinder.

The principle of grinding, as applied to reciprocating table type surface grinders, is illustrated by means of the diagrams of relative movements in figures. A reciprocating table type surface grinder may have a horizontal spindle of the grinding wheel (See Figure) or a vertical spindle of the same, as shown in figure. The former will carry a straight wheel and the latter a cup type wheel. Hydraulic drives are commonly used in all such grinders. Cutting is done on the periphery of the straight wheel, in case of horizontal spindle type, and on the revolving edge of the cup wheel on vertical spindle machines. The horizontal spindle machines are widely used in tool rooms. The workpiece is usually held on a magnetic chuck on these machines. They are vastly used for grinding flat surfaces. The machine size is designated by the dimensions of the working area of the table.

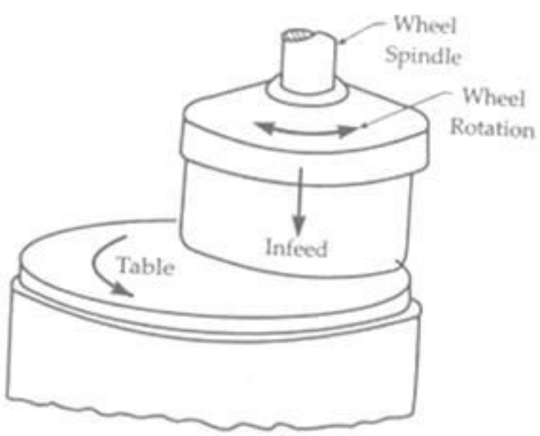
The longitudinal feed to the work is given by reciprocating the table. For giving cross feed, there are two methods. One is to mount the table on a saddle and given the cross feed by moving the saddle. Alternatively, the cross feed can be given by moving the wheel-head in and out. In feed is provided by lowering the wheel head along the column.

In case of vertical spindle reciprocating table grinders the table, along with the workpiece, reciprocates under the wheel. The wheel covers all or a major portion of the width of the job, as shown in figure. Cross feed to the work can be given as usual by moving the saddle. A manual or power feed can be employed to feed the wheel-head vertically. An individual motor drive is usually provided to rotate the wheel.

Rotary Tab le Surface Grinders



Relative movements of different parts of a Horizontal Spindle Rotary Table Surface Grinder.



Relative movements of different parts of a Vertical Spindle Rotary Table Surface Grinder

Rotary table surface grinders are also made in two types, i.e., either having a horizontal wheel spindle or a vertical wheel spindle. The relative movements of the wheel and table of a horizontal spindle type are shown in Figure. Usually a circular shaped magnetic chuck is mounted on the circular table to hold the jobs. The work pieces are normally arranged in a circle, concentric with the round chuck. If it is a single piece, it can be mounted centrally on the chuck. The table is made to rotate under the revolving wheel, both rotating in opposite directions. The vertical feed to the wheel is given by moving the wheel-head along a column and the cross feed by the horizontal movement of the wheel spindle. A straight wheel is used on these machines, which cuts on its periphery. Some machines carry the provision to raise or lower the table also, and also to incline the same.

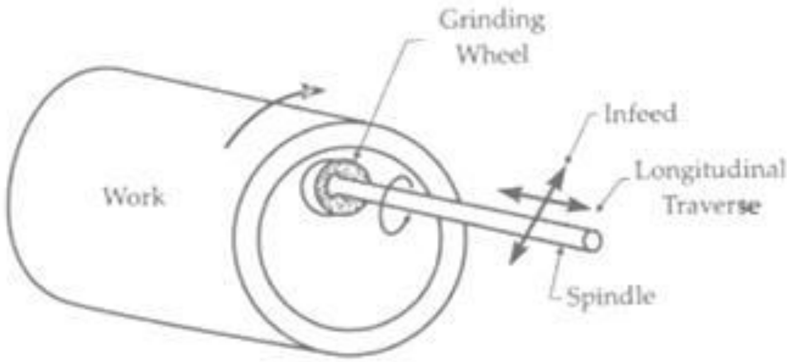
Figure illustrates the relative movements of the wheel and table of a Rotary table vertical spindle surface grinder. A cup wheel has to be used on these machines, as shown in the diagram. Vertical feed to the wheel is given by moving the wheel-head. The work pieces are mounted on the round chuck in the same way as in the horizontal spindle type. The table rotates in a direction opposite to that of the wheel and brings the work pieces one after the other under the rotating wheel. The table is usually mounted on a slide so as to give cross feed. Some rotary table surface grinders are provided with two tables instead of one so that, while the work pieces are being ground on the table, the other table can be used for loading the fresh batch of work pieces.

Internal Grinders

These are the machines used for grinding the internal surfaces of different types of holes, viz., cylindrical, tapered and formed, etc. The hole to be ground may be through or blind. Most of these machines are horizontal, although a few with vertical spindles are also available. These machines are made in various types and designs and operate on different principles. Principal types of these machines are the following:

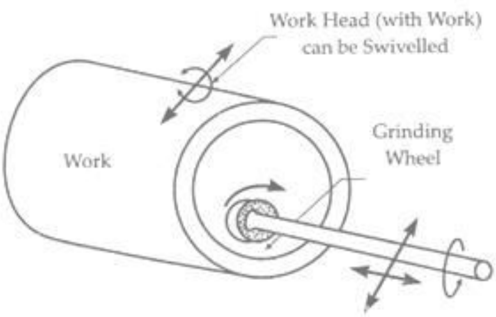
- Plain internal grinders
- Universal internal grinders
- Chucking internal grinders
- Centre less internal grinders
- Planetary internal grinders

1. **Plain Internal Grinders**



A plain internal grinder carries an individually driven wheel-head mounted on a cross-side. The work head either carries a chuck or face-plate to hold the work or the latter can be mounted on a fixture attached to the work head spindle. The work-head can be swivelled to grind tapered holes. When the work is too large the principle of planetary grinding is employed. The principle of operation and relative movements of grinding wheel and work are shown in figure.

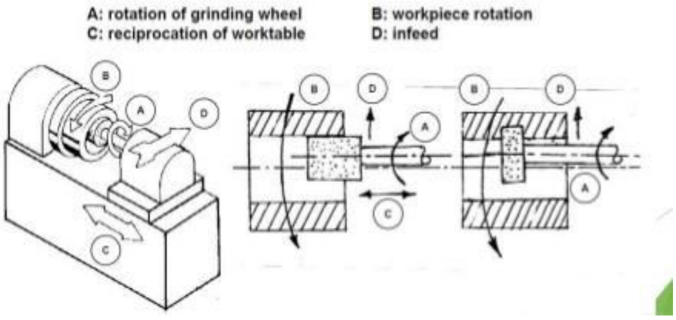
2. **Universal Internal Grinders**



The Universal internal grinder carries all the features of a plain internal grinder and, in addition to that, its workhead is mounted on a cross-slide which enables a crossfeed to the workhead. Another important feature in these grinders is that the workhead can be swivelled through 90°. These grinders can be used to grind cylindrical and tapered holes, flat surfaces, outside cylindrical surfaces, convex and concave surfaces, etc. The relative movements of work and grinding wheel are shown in Figure.

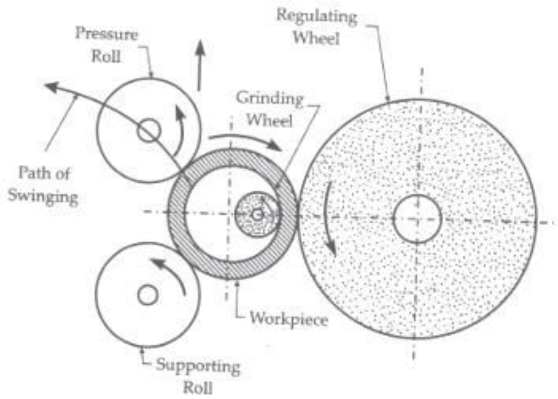
3. Chucking Internal Grinders

The workpiece is usually mounted in a chuck. A magnetic face plate can also be used. A small grinding wheel performs the necessary grinding with its peripheral surface. Both transverse and plunge grinding can be carried out in this machine.



The Chucking internal grinder is provided with a reciprocating table, which carries the work head. The wheel head is mounted on a cross-slide on the bed. The work is moved towards and away from the wheel and also fed across it. A gap grinder serves the same purpose as a gap bed lathe. This type of grinder carries a gap in the bed, which enables the larger size jobs to be ground. The duplex grinder carries two reciprocating wheel-heads and a workhead between them. Two opposite holes with perfect alignment can be ground simultaneously on this machine.

4. Centre less Internal Grinders



Set up for Centreless Internal Grinding, showing relative motions of different components.

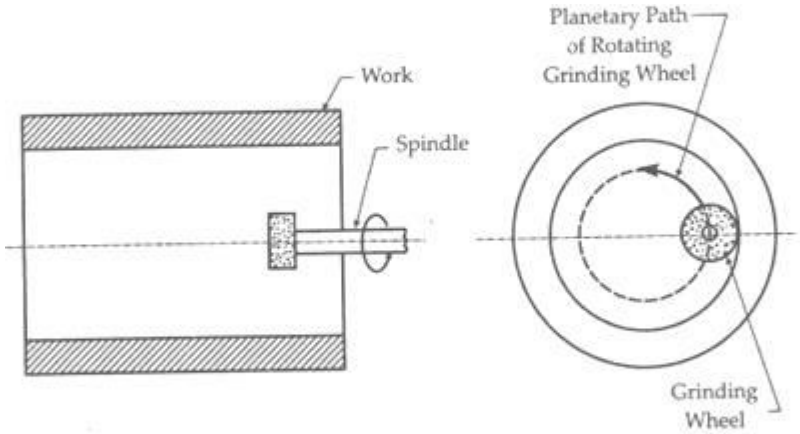
The principle of internal centre less grinding is more or less similar to external cylindrical grinding. The main difference lies in the method of supporting the work. In an internal centre less grinder the workpiece is supported between three rolls, a pressure roll, a supporting roll and a regulating wheel, as shown in figure. These rolls, while supporting the workpiece, also rotate the same. All the three rolls rotate in the same direction, while the workpiece and the grinding wheel rotate in the opposite direction. The grinding wheel remains in contact with the internal surface of the workpiece at the horizontal centreline of the regulating wheel. This ensures a uniform wall thickness of the workpiece and, therefore, concentricity of the ground internal hole (bore) with the external surface of the workpiece. The pressure roll is so mounted that it can be swung to a side to allow loading and unloading of the work pieces. The wheel head is mounted on a slide and can be given a reciprocating motion by hand to feed the grinding wheel in and draw it out after completion of the operation.

5. Planetary Internal Grinders

These grinders are primarily designed to grind holes in large, irregular shaped and heavy work pieces. In planetary grinding the workpiece remains stationary, which is mounted on a slide. The wheel head carries a mechanisms, due to which the axis of the rotating grinding wheel travels along a circular path around the axis of the hole in the workpiece, as shown in Fig.12.29. The longitudinal traverse can be obtained in the following two ways:

a) By reciprocating movement of the grinding wheel spindle, as shown in Fig.12.29.

b) By moving the slide, forward and backward, on which the workpiece is mounted.



The spindle of the grinding wheel is given a radial in feed after completion of each planetary circle to increase the depth of cut.

A common important point with all the internal grinders is that the grinding wheels used on these machines are much smaller than those used on cylindrical or surface grinders. As such, their spindles are operated at much higher speeds, so as to obtain the required surface speeds.

Tool and Cutter Grinders

Tool and cutter grinders are used mainly to sharpen and recondition multiple tooth cutters like reamers, milling cutters, drills, taps hobs and other types of tools used in the shop. With various attachments they can also do light surface, cylindrical, and internal grinding to finish such items as jig, fixture, die and gauge details and sharpen single point tools. They are classified according to the purpose of grinding, into two groups.

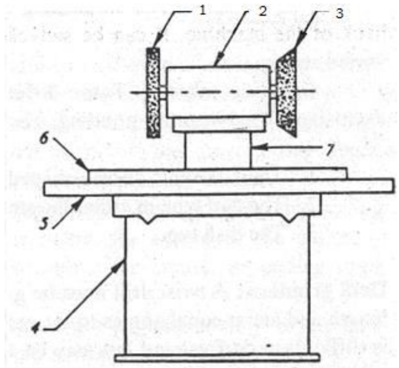
1. Universal tool and cutter grinder
2. Single-purpose tool and cutter grinders

Universal tool and cutter grinders are particularly intended for sharpening of miscellaneous cutters.

Single-purpose grinders are used for grinding tools such as drills, tool-bits, etc. in large production plants where large amount of grinding work is necessary to keep production tools in proper cutting condition. In addition, tools can be ground uniformly and with accurate cutting angles. A typical tool and cutter grinder is shown in Figure.

Universal tool and cutter grinders:

The universal tool and cutter grinders made by different manufacturers vary more or less as to details, but they are similar in their general arrangement and operate on the same general principle.



Block diagram of a

tool and cutter grinder

1. & 3. Wheel 2. Wheelhead, 4. Base, 5. Saddle, 6. Table, 7. Column.

The grinder has the following principal parts.

Base: The base 4 gives rigidity and stability to the machine. It is heavy, rugged and box-type.

Saddle: The saddle 5 is mounted directly on the top of the base. Moves on antifriction ball bearings on hardened ways. The column supporting the wheel head is mounted on the saddle and it can be moved and down and swiveled to either side. The saddle also provides the mean for moving the work forward and backward.

Table: The table 6 rests and moves on a top base which is mounted over the saddle. The top of the base contains the gears and mechanism which control the table movement.

The work table is mounted on the sub-table which has T-slots for monting the work and attachements used on the machines. The work table can be swivelled which enables the operator to grind tapers.

Headstock and tailstock: The headstock and tailstock are mounted on either side of the table similar to those on a cylindrical grinder. The workpiece is positioned between the centres and driven exactly as in a cylindrical grinder.

Wheel head: The wheelhand 2 is mounted on a column on the back of the machine. It can be swivelled and positioned on the base for varied setups.

Grinding wheel: Three different types of grinding wheels are extensively used in cutter grinding. These are:

1. The “straight” or disc-shaped wheel.
2. The cup type in either the straight or flaring form.
3. The dish type.

Drill grinders: A twist drill must be ground so that the lips have the same length and are at equal angles to the axis if the tool is to cut properly. This is difficult to do freehand but may be accomplished easily on a drill-point grinder.

Size and specifications of grinding machines

The size of a grinder is specified according to:

i. The largest workpiece which can be held on a grinder.
ii. The normal capacity (or power) of the grinder.
iii. The width of the table.
iv. The maximum traverse of the table.
v. Wheel diameter.
vi. Height of the grinding head etc.

Grinding Wheel

- A grinding wheel is a multi-tooth cutter made up of many hard particles known as 'abrasive' which have been crushed to leave sharp edges which do the cutting. The abrasive grains are mixed with a suitable bond which acts as a matrix or holder when the wheel is in use.
- The wheel may consist of one piece or of segments of abrasive blocks built up into a solid wheel.
- The abrasive wheel is usually mounted on some form of machine adapted to a particular type of work.

The performance of a grinding wheel is usually evaluated in term of the grinding ratio (G) which is defined as :

$$G = \frac{Volume\ of\ material\ required}{Volume\ of\ wheel\ wear}$$

For fine grinding operations such as horizontal surface grinding, the value of G is usually in the range of 10 to 60, while for rough grinding operations it is much less than 10.

Characteristics of the grinding wheel:

Wheel parameters that influence the grinding performance are :

1. Abrasive material
2. Abrasive size
3. Bond
4. Grade.
5. Structure.

1. Abrasive material

An 'abrasive' is a substance that is used for grinding and polishing operations.

Abrasives may be classified as follows :

1. Natural :
   (i) Sandstone (ii) Emery
   (iii) Corundum (iv) Diamonds.
2. Artificial :
   (i) Silicon carbide (ii) Aluminum oxide.

Natural abrasives :

Almost all of the natural abrasives, except diamond are now considered obsolete.

- The "sandstone" is used only for the sharpening wood-working tools.
- "Emery and corundum" are the materials which were widely used formerly but now these have been replaced completely by artificial abrasives.
- "Diamond" is largely used for dressing the grinding wheels and as an abrasive for grinding hard materials.

Artificial abrasives:

(i) Silicon Carbide (SiC) :

- Silicon carbide abrasive is manufactured from 56 parts of silicon sand, 34 parts of powered coke, 2 parts of salt, and 12 parts of saw dust.

- There are two types of silicon carbide abrasives :
  (a) Green grit which contains at least 97% silicon carbide.
  (b) Black grit which contains at least 95% silicon carbide.
- It follows the diamond in order of hardness, but it is not as tough as aluminum oxide.
- It is employed for grinding materials of low tensile strength such as cemented carbide, stone and ceramic materials, grey cast iron etc.

(ii) Aluminum oxide (Al_2O_2) :

- It is manufactured by heating mineral bauxite a hydrated aluminum oxide clay containing silica, iron oxide, titanium oxide etc., mixed with ground coke and iron shavings in an arc-type electric furnace.
- As it is tough and is not easily fractured, it is better adopted to grinding materials of high tensile strength, such as carbon steels, high speed steels, tough bronzes etc.

Abrasive Size :

Choice of the grain size depends upon the properties of the work material, surface finish, desired rate of metal removal etc.

- Coarse grains (grit size 10-24) give faster rate of metal removal, but yield a poor surface whereas fine grits (grit size 70-180) are used for finishing operation but the rate of metal removal is slow.
- Coarse grain wheels are normally suitable for soft and ductile materials; for hard and brittle materials finer grains are preferred.

3. Bond :

To ensure an effective and continuous action, it is imperative that the grains of abrasive material should be held firmly together to form a series of cutting edges. The material used for holding them is known as Bond. The principal bonds are enumerated and described below :

(i) Vitrified bond	(ii) Silicate bond
(iii) Oxychloride bond	(iv) Resinoid bond
(v) Shellac bond	(vi) Rubber bond.

(i) Vitrified bond :

- It is a clay bond, reddish brown in color.
- The base material is Felspar which is a fusible clay.
- The bond itself is very hard and acts as an abrasive.
- It is not affected by water, oil, acids, temperature or climatic conditions.
- The structure of the wheel is uniform due to wet mixing of different components.
- Most of the grinding wheels possess this bond.
- Such bonds are abbreviated as V.

(ii) Silicate bond :

- The base material of this bond is silicate of soda.
- Wheels possessing this bond are light grey in color.
- In this case, the cutting action of the wheel is smoother and cooler.
- Extra hard wheels cannot be produced with this bond.
- Such wheels are designated by the letter S.

(iii) Ox chloride bond :

- It is a mixture of oxide and chloride of magnesium and setting takes place in cold state.
- This bond provides a cool cutting action, but grinding is usually done dry.
- Such bonds are abbreviated as O.

(iv) Resinoid bond :

- It is made out of synthetic or organic resin.
- It is strong and flexible.
- Wheels made from such a bond can be used for high speed cutting at low temperatures.
- The bond is addressed by the letter B.

(v) Shellac bond :

- This bond is used for high finish work.
- It is designated by the letter E.

(vi) Rubber bond :

- Rubber bond wheels are composed of hard vulcanized rubber.
- Such wheels are hard flexible and can have very thin sections and are useful in cut-off operations.
- Use of cutting fluid is essential with such wheels.
- Rubber bond is abbreviated as R.

4. Grade :

'Grinding wheel grade' refers to the strength with which the bond holds the grains together.

- The strength or hardness of the wheel depends upon the volume of the bonding material used. As the volume of the bonding material in a wheel increases its hardness improved.
- The wheel hardness is designated as soft, medium or hard. Wheel with hardness rating A to I are classified as soft, those having a rating of J to P are medium and wheels with hardness rating Q to Z are hard.

5. Structure :

'Structure' of a grinding wheel refers to the relationship between the volume of the abrasive material, volume of bond and the volume of voids present in a grinding wheel.

- A wheel would have a dense structure when the percentage volume of the abrasive is large.

Specification: The American standard specifies the grinding wheels as follows:

1. Abrasive type : A for Alumina, S for Silicon carbide etc.
2. Grain size : mesh number
3. Grade : Letters A for very soft, and Z for very hard.
4. Structure: 15 for very dense structure.
5. Bond type: V-vitrified, R-rubber etc.
6. Manufacturer's owned private mark.

Thus, a wheel marked as follows:
A-50 Q15 V-30
represents an alumina wheel with 50 grit size, medium hardness, open structure and vitrified bond. The number 30 at the end is manufacturer's own identification number.

Selection of Grinding Wheels

Selection of a proper grinding wheel is a vital necessity to obtain the best result in grinding work. A wheel may be required to perform various different functions like quick removal of stock material, give a high class surface finish, maintain close dimensional tolerances and a single wheel will fail to meet all the requirements. It is necessary; therefore, that proper grain size, bond, grade, strength, shape and size of the wheel should be selected to meet the specific requirements of a job. The factors upon which the above selection will depend are as follows:

- Properties of the material to be machined, i.e., its hardness, toughness, strength, etc.
- Quality of surface finish required.
- Grinding allowance provided on the workpiece, i.e., the amount of stock to be removed.
- Dimensional accuracy required.
- Method of grinding, i.e., wet or dry.
- Rigidity, size and type of machine.
- Relative sizes of wheel and job.
- Type of grinding to be done.
- Speed and feed of the wheel.

Loading and Glazing Of Grinding Wheels

After continuous use of the grinding wheel the sharp points (cutting points) of the abrasive grains become dull. They lose their cutting ability and sharpness and are severely worn-out. Consequently, the wheel face becomes smooth and it, instead of biting into work material, provides a sort of rubbing action only. The above phenomenon, which renders the wheel unuseful, is called Glazing of grinding wheel, and is more predominant in hard wheels and at higher speeds. With softer wheels and relatively slower speeds, this effect is less prominent. The grinding wheel so affected is called a Glazed Wheel.

Another problem associated with the grinding wheels in operation is the adherence of the cut particles of the work material to the face of the grinding wheel. These particles occupy the open space between the cutting points. Due to this, the sharpness of the cutting points is lost and the face becomes smooth, depriving the wheel of its cutting points is lost and the face becomes smooth, deriving wheel of its cutting ability. This phenomenon is known as loading of wheel and the effected wheel is called 'Loaded' wheel. This effect is seen more prominently with those wheels which carry a hard bond, when softer materials are ground and while slower cutting speeds are used. Very deep cut also contributed towards this effect.

Truing and Dressing the Grinding Wheels

It is just a matter of common sense that a produced surface cannot be more true than the trueness of the grinding wheel producing it. Also, is equally true that the full cutting capacity of a grinding wheel cannot be fully utilized if its periphery has gone dull or got clogged with some foreign material. It is for these reasons that the operations of truing and dressing are performed.

The truing operation is done to make the periphery of the wheel concentric with its axis, make its sides true and to recover the lost shape of its face. Dressing of the wheel is done to recover the proper cutting action of the wheel face by renovating the same by removing the layer of dulled grains or grains clogged with foreign material. As explained earlier, the latter defect is known as loading and the grains affected as loaded, whereas the formed defect is called glazing and the effected wheel face as glazed. How often a wheel is to be trued or dressed will depend upon the type of work, operator's skill and the wheel fitness, viz., a frequency truing is always required in internal grinding whereas it is not so in external grinding. The following are the common devices used for dressing of grinding wheel:

- Wheel dressers
- Abrasive wheels,
- Crush dressing fixtures.
- Abrasive sticks
- Diamond, and

Methods of Grinding

Most of the grinding operations have already been explained earlier along with the grinding machines used for them.

1. **Cylindrical grinding**
   It means grinding of outside cylindrical and tapered surfaces.

2. **Internal grinding**
   It means a method of grinding the internal surfaces of cylindrical or tapered holes.

3. **Surface grinding**
   It is a method of grinding horizontal flat surfaces. The wheel spindle can be horizontal or vertical.

4. **Face grinding**
   It is a method of grinding vertical flat surfaces. Again, the wheel spindle can be horizontal or vertical.

5. **Set wheel grinding**
   It is a method of grinding relatively short work pieces without changing the cross setting of the wheel once set.

6. **In feed or plunge cut grinding**
   It is also a method of grinding very short work pieces. It involves the use of a grinding wheel having its face wider than the length of the surface to the ground and feeding the same into the work with no traversing motion of it.

7. **Form grinding**
   It is a method of producing formed surfaces through grinding. The wheel face is given the desired shape by dressing and then fed on to the work surface, as in case of thread grinding and gear teeth grinding.

8. **Centre less grinding**
   It is a method of grinding external cylindrical surfaces, in which the work is supported among a regulating wheel, a grinding wheel and a work rest blade.

9. **Snagging**
   It is an operation used for grinding the gates, spurs and fins on castings, finishing forgings, and removing scale, imperfections and excess metal from steel billets and welded structures. Primary requirement, obviously, is the removal of metal and not the type of surface finish. The workpiece is not rigidly mounted or clamped in any device. Feeding can be in two ways, i.e., either the workpiece to the grinding wheel or the wheel on to the work surface. In either case, the feeding is done usually by hand.

10. Off-hand grinding

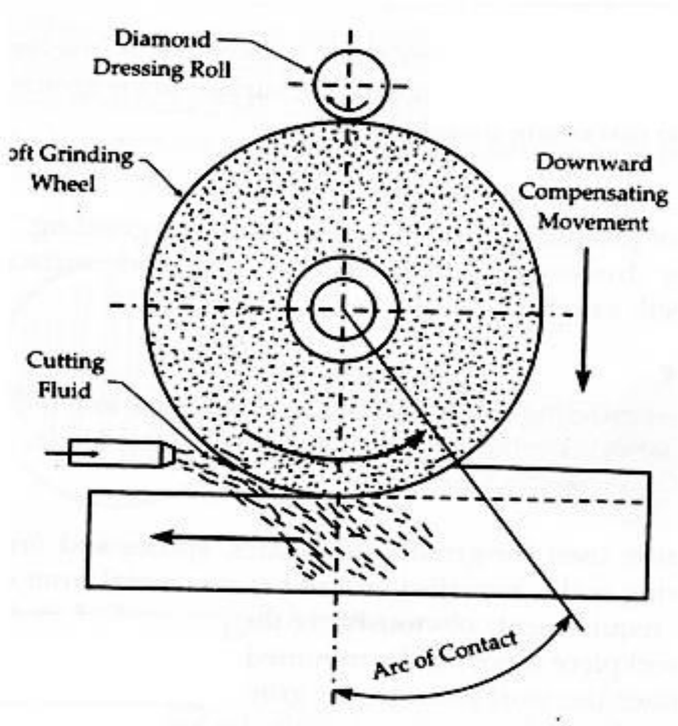
It is a rough grinding method in which the work is held in hand and pressed against the rotating grinding wheel. This method is commonly used for grinding of such items in which accuracy and surface finish are not of primary importance, such as in sharpening cutting edges of chisels, etc.

11. Sharpening cutting tools

Several cutting tools, including single point tools, milling cutters, drills, reamers, hobs, etc., need regrinding quite often to provide them correct geometry, restore lost geometry and sharpen their cutting edges.

12. Creep feed grinding

It is a method in which a soft grinding wheel is used. The wheel revolves in position while the work is fed past this revolving wheel at a very slow speed. Multiple passes are avoided and the entire depth of material to be removed is removed in a single pass. Ample amount of coolant, usually sulfurised oil, under pressure, is used in the process. Dressing of the grinding wheel is continuously done during the process, for which a diamond-coated dressing wheel (roll) is mounted above the grinding wheel. Due to continuous dressing the wheel is likely to go undersize. Therefore, a mechanism continues to press it downwards to compensate for the lost size and maintain the same depth of cut throughout. The operation is shown in figure.



SPEED FEED AND DEPTH OF CUT

In case of grinding work, the term 'Cutting Speed' refers to the peripheral speed of the grinding wheel relative to the speed of the workpiece. It is usually expressed in meters per second and can be expressed thus :

$$V = \frac{\pi DN}{1000 \times 60} m/sec$$

Where V=Peripheral speed of the grinding wheel in m/sec.

D=Diameter of the grinding wheel in mm.

N=r.p.m. of the grinding wheel.

Feed

In cylindrical grinding, the term 'feed' denotes the axial movement of the workpiece in its each revolution. If 'f' be the said feed, 'b' the width of the face of the grinding wheel, then;

f=C bmm/rev. of workpiece.

Where, C=a constant, depending upon the type of grinding being done, i.e., rough grinding or finish grinding.

The values of 'C' for the two types of grinding are as follows:

Rough grinding $\longrightarrow$ 0.6 to 0.9

Finish grinding $\longrightarrow$ 0.4 to 0.6

Now, the work or table travel can be calculated as follows:

$$\left.\begin{array}{l}\text{Work travel}\\ \quad\text{or}\\ \text{Table travel}\end{array}\right\} = \frac{f \times n}{1000}\ meters/min$$

where, f=feed in mm/rev.

n=r.p.m. of the workpiece

Depth of Cut

It represents the thickness of the metal removed by the grinding wheel in one pass or one longitudinal traverse. It is given by :

$$t = \frac{D_1 - D_2}{2} \text{mm}$$

where t=depth of cut in mm

D_1=workpiece dia. before grinding

D_2=workpiece dia. after grinding

The normal 'depth of cut' in grinding varies from 0.005 mm to 0.04mm, depending upon the type of grinding, work material, bond, etc. smaller values are adopted for finish grinding and higher values for rough grinding. The common ranges are:

For finish grinding = 0.005 mm to 0.015 mm

For rough grinding > 0.015 mm.

Machining Time in Grinding

The machining time (7) in cylindrical grinding can be calculated from the following relationship

$$T = \frac{L.P.K}{f.n.t} \text{min}$$

where L=Longitudinal travel in one pass (in mm)

P=Number of passes made

f=Longitudinal feed/rev. (in mm)

n=r.p.m. of the workpiece

K=a constant (Accuracy Factor), depending upon the degree of a accuracy and level of surface finish. =1.0 to 1.2 for rough grinding (commonly used value=1.1) and =1.3 to 1.7 for finish grinding (commonly used value=1.4)

In case of plumage cut cylindrical grinding, the machining time (T) is given by:

$$T = \frac{a \,.\, k}{f_c \,.\, n} \text{ min}$$

where a=grinding allowance on each side in mm.

f_c=cross feed in mm/rev.

n=r.p.m. of the workpiece

K has the same significance as in case of cylindrical grinding.

Broaching

Introduction

Broaching is a machining operation in which a tool, having a series of cutting teeth, called Broach, is either pulled or pushed by the broaching machine past the surface of a workpiece. In doing so, each tooth of the tool takes a small cut through the metal surface. The surface to be cut may be external or internal. When the operation is performed on internal surface it is called internal or Hole Broaching and in case of external surface External or Surface Broaching. Most of the cutting is done by the first and intermediate teeth whereas the last few teeth finish the surface to the required size.

Details of Broach Construction

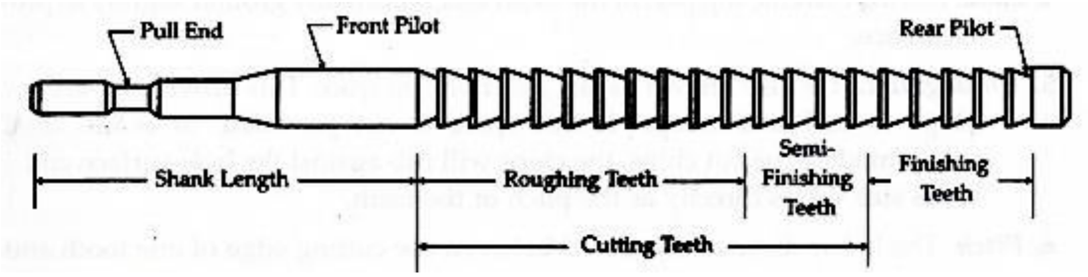
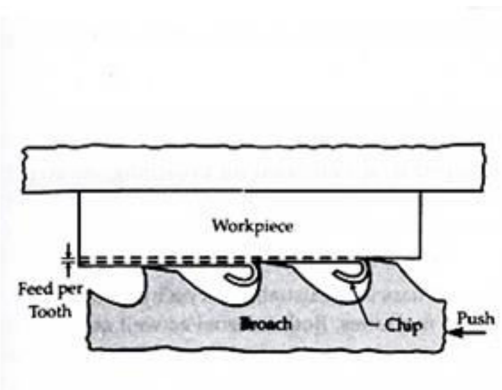
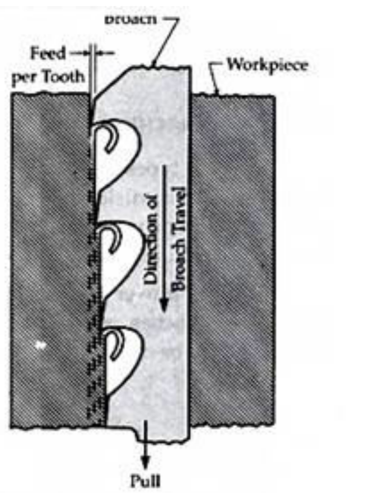


Figure illustrates the details of a pull type hole or internal broach for producing a cylindrical hole. The puller grips the broach at the shank end. Before the teeth, the front pilot enters the hole to keep proper alignment. The cutting teeth, which follow the front pilot, gradually increase in size. The first set of cutting teeth, called roughing teeth, does most of the cutting. They are followed by semi-finishing teeth, which remove comparatively less stock than the former. The variation in their sizes will obviously be smaller than the roughing teeth. They bring the size of the hole to roughly the required size. The finishing teeth, which follow after the semi-finishing teeth, do not practically remove any appreciable amount of stock. They are all of the same size and shape as the required size and shape of the hole, so as to produce the hole of required size and shape having a smooth finish. When the first finishing teeth are worn out, those behind them start doing the sizing operation. The rear pilot supports the broach and keeps it aligned after the cut is over.

Principle of Broaching



A Push type Broach in use for Machining an external surface.



A Pull type Broach in use for Internal broaching on a vertical pull-down type machine.

The operation of broaching involves the use of a multitooth cutter, called broach, which has already been described earlier. The teeth of the broach are so designed that the height of the cutting edge of the following cutting tooth is slightly more, equal to the feed per tooth, than that of the preceding tooth. Thus, when the broach is fed in a straight line, either over an external surface or through an internal surface, the metal is cut in several successive layers by successive teeth of the broach. The thickness of each layer is same and is known as feed per tooth. The sum of thicknesses of all the layers taken together is called the depth of cut.

During the operation, either the broach is fed past the stationary workpiece or the workpiece past a stationary broach, the former practice being more common. The surface produced carries an inverse profile to that of the broach teeth. A specific point regarding broaching is that out of all the basic machining processes it is the only process in which the feed is in-built in the tool (broach). This feed is equal to the chip thickness. This aspect is amply clear in the given diagrams.

Figure shows a push type broach being fed past the stationary work, on a horizontal broaching machine, to machine an external surface on the workpiece. Figure shows a pull type broach being fed into a hollow workpiece, on a vertical pull-down type machine, to machine an internal surface of the workpiece. In this case also, the workpiece will remain stationary. Both the operations are performed in a single linear stroke of the broach. After the end of the stroke in both the above operations the broach is retracted to the original starting position, the finished part replaced by a new workpiece and the operation repeated as usual.

Lapping

It is an abrading process employed for improving the surface finish by reducing roughness, waviness and other irregularities on the surface. It is used on both heat-treated and non-heat-treated metal parts. It should, however, be noted that where good appearance of the job surface is the only requirement, it should not be employed, since there are other finishing methods which will give the same desired result with low cost. It should be used only where accuracy is a vital consideration in addition to the surface finish. The basic purpose of lapping is to minimize the extremely minute irregularities left on the job surface after some machining operation.

In brief, we can say that lapping is basically employed for removing minor surface imperfections, obtaining geometrically true surfaces, obtaining better dimensional accuracy and, thus, facilitate a very close fit between two contacting surfaces.

The material to be selected for making a lapping tool or lap largely depends upon the individual choice and the availability, and no specific rule can be laid for the same. The only consideration that has to be made is that the material used for making a lap should be soft so that the abrasive grains can be easily embedded in its surface. In case a hard material is used for making a lap, the abrasive particles will quickly go out of their places. The commonly used materials are soft cast iron, copper, brass, lead and sometimes hardwood.

Abrasive. All the abrasives, i.e., natural as well as artificial are used for lapping. Aluminum oxide is preferred for lapping soft ferrous and non-ferrous metals. Silicon-carbide and natural corundum are used for hardened steel parts. Powdered garnet is used for lapping soft ferrous and non-ferrous metals, emery for hardened steel components and diamond for extremely hard materials like cemented carbides.

Vehicle. The term ‘vehicle’ in lapping denotes the lubricant used to hold or retain the abrasive grains during the operation. To some extent it also controls the cutting action of the latter. Some common vehicles used in lapping include the vegetable or olive oil, lard oil, water soluble oil, mineral oil, kerosene mixed with a little machine oil, alcohol, and heavy grease. For cleaning the laps, naphtha is commonly used. No specific recommendations can, although, be laid for the selection of a particular vehicle. Still the vehicle used should possess the following qualities:

1. It should be able to hold the abrasive particles uniformly during the operation.
2. Its viscosity should not be considerably affected by temperature changes.
3. It should not evaporate quickly.
4. It should be non-corrosive.
5. Its viscosity should suit the operating speeds.

Lapping allowance: As already described earlier, the lapping operation is not primarily meant for removing metal. As such, enough care should be taken to ensure that too much material is not left on the work surface to be removed by lapping. The endeavour should always be to obtain as good surface finish through earlier machining operations as it is possible to that a very negligible amount of stock remains to be removed by lapping. It should be borne in mind that smaller the amount of stock left, quicker will be the lapping process and higher will be the dimensional accuracy obtained. Keeping in view the above discussions, the recommended range of lapping allowance to be left is as follows:

1. General lapping work

Allowance on surface 0.0075 mm to 0.0125mm

Allowance on dia or thickness 0.015 mm to 0.05mm

2. For lapping the work which has been finish ground

Allowance on surface 0.005mm

Allowance on dia. 0.01mm

Pressure and speed for Lapping

The following magnitudes of pressures are recommended for lapping:

For soft materials 0.07-0.2 kg/cm^2

For hard materials 0.7 kg/cm^2

Normal speed range used in rotary lapping, i.e., when the work and lap have a rotary motion relative to each other, varies from 1.5m/sec to 4.0m/sec.

Types of Lapping Operations

Lapping operations can be broadly classified into the following two main groups:

- Equalizing Lapping
- Form Lapping

1. Equalising Lapping

It is the operation of running two mating parts or shapes together with an abrasive between them. When two such surfaces run together in constant contact with the abrasive, their surface finish is improved and any deviation of shape corrected. Those results can be easily seen during seating of tapered valves in their seats or when gears are rotated together with these objectives.

2. Form Lapping

As is clear from the name itself, it is not merely rubbing of surfaces together but it is the shape of the lap that is responsible for finishing a corresponding work surface. Obviously, the lap used in the operation will be a form lap, i.e., containing the shape to be lapped.

Honing

It is also an abrading process, used for finishing previously machined surfaces. It is mostly used for finishing internal cylindrical surfaces such as drilled or bored holes. The tool used, called a hone, is a bonded abrasive stone made in the form of a stick. Although honing enables the maximum stock removal out of all the surface finishing operations, still it is not primarily a metal removing operation. However, this higher stock removing capacity enables the application of honing for correcting slight out of roundness or taper. Hole location cannot be corrected through it. The usual amount of stock left for removal by honing is form 0.1mm to 0.25mm, although it is capable of removing the stock up to 0.75mm. Honing is performed at relatively slow speeds in the range of 10-30 meters/min.

The honing tool works more or less in the same way as an expanding reamer. The honing stones are so held in a holder or mandrel that they can be forced outwards by mechanical or hydraulic pressure against the surface of the bore. Aluminum oxide, silicon carbide or diamond grains of suitable grit are bonded in resinoid, vitrified or shellac bond to form the honing stones, usually carrying impregnated traces of sulphur or wax for longer tool life and better cutting action. Both internal cylindrical and flat surfaces can be honed. But, the process of honing is largely applied to internal cylindrical surfaces only. A hand honing tool is shown in Figure.